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CONTENTS

ORIGINAL ARTICLE

Effects of circuit training method on reactive agility and endurance in table tennis players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim: Reactive agility and aerobic endurance are crucial physical components for athletes' success in both competitions and training. However, traditional training programs often fail to simultaneously address both components effectively. The purpose of this study was to determine the effect of a training type using the circuit method to improve reactive agility and aerobic endurance.

Material and Methods: This research is an experimental study employing a pre-experimental one-group pretest-posttest design. The participants were fourteen junior male athletes aged 15 to 17 years. The training program was conducted three times a week for six weeks and included eight different exercises. The instruments used were table tennis reactive agility measuring devices and the beep test for assessing aerobic endurance. Data were analyzed using the paired sample T-test.

Results: The results of the data normality test showed a significance value (Sig.) greater than 0.05, indicating that the data were normally distributed and suitable for further analysis. Subsequent testing for the effectiveness of the exercise regimen using the paired sample T-test revealed significant improvements: reactive agility and aerobic endurance both achieved a p-value of 0.000.

Conclusions: The findings indicate that circuit training, involving eight types of exercises, significantly improved the athletes' reactive agility and aerobic capacity. Specifically, there was a notable average increase in both reactive agility and aerobic capacity following the training regimen. These results underscore the potential benefits of employing the circuit training method with eight diverse exercises to enhance performance in table tennis athletes.

Keywords: reactive agility, aerobic, table tennis, circuit training

Introduction

In competitive table tennis, reactive agility and aerobic endurance are critical factors that can significantly influence a player's performance. Despite their importance, traditional training methods often overlook the integration of these elements, limiting the potential for optimal athletic development. This gap highlights the need for innovative training strategies that effectively combine agility and endurance training to meet the demands of high-level competition.

Table tennis is a sport that demands quick movements and rapid adjustments in position, requiring players to execute complex movements and techniques within very short time frames [1]. To enhance their performance, table tennis athletes must excel not only technically and psychologically, but also physically [2]. Physical prowess is paramount, with several key components impacting athlete performance during competitions, particularly reactive agility and aerobic endurance [3]. A frequent issue is that athletes often struggle with reacting to long balls, attributable to suboptimal agility and reaction times. Khairil et al. [4] noted that reactive agility is a synthesis of agility and reaction time, essential for addressing common challenges in table tennis, such as decision-making difficulties and swift movement while maintaining balance.

Reactive agility is a crucial parameter for table tennis performance [5]. This performance is characterized by rapid movements, frequent changes in direction, and the execution of complex maneuvers that are challenging to perform. Specifically, table tennis requires quick directional changes in response to stimuli [6]. The necessity for high-speed directional changes is further compounded by the relatively narrow playing field, measuring 274 cm in length and 152.5 cm in width, which contributes to the high bounce of the ball from any player's shot. Furthermore, players must quickly and accurately respond to their opponents' unexpected movements. Additionally, the sport demands the execution of fast and irregular strokes, requiring high levels of performance [7].

Aerobic endurance is also a critical component of table tennis [8]. It is defined as the ability of an athlete's body to resist fatigue during prolonged sports activities or work and to recover swiftly [9]. However, athletes often encounter fatigue during practice sessions, and during matches, especially in rubber sets, they begin to lose focus. This loss

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of focus is primarily due to inadequate endurance, which leads to rapid exhaustion and impaired concentration. Therefore, improving endurance based on the specific demands of table tennis is essential.

Previous research has demonstrated the effectiveness of the Circuit Training method in enhancing endurance capabilities [10, 11, 12]. Similar studies have focused on the application of the circuit method to improve the physical abilities of athletes in specific sports [13, 14]. Circuit training consists of a series of systematic exercises performed at various stations, each with a predetermined training dose and duration. These exercises are tailored to meet the individual needs of athletes and typically involve 5 to 8 stations [11, 15, 16].

However, existing problems related to agility and response time have hindered the optimization of training programs and the effectiveness of tests measuring reactive agility. Thus, it is crucial to find solutions to enhance reactive agility performance, which is a key indicator for improving table tennis performance [5]. Although some studies have focused on improving specific aspects of performance necessary for table tennis, few have addressed the combined impact of multiple performance factors. For example, some research has tailored circuit training to improve aerobic capacity [12], while others have tested its effects on agility, anaerobic capacity, strength, and endurance [17, 18]. Many studies have explored the adjustments in physical activity programs through circuit training, specifically targeting agility, anaerobics, strength, and endurance. Overall, it can be concluded that circuit training is an exercise regimen consisting of a series of consecutive exercise stations designed to meet various physical demands.

Research Hypothesis: It is hypothesized that circuit training, involving eight types of exercises conducted three times a week for six weeks, can enhance the reactive agility and aerobic endurance of table tennis athletes, thereby improving their overall physical capabilities.

The purpose of this study is to examine the effects of the circuit training method on the reactive agility and aerobic capacity in table tennis performance.

Materials and Methods

Participants

The study included 14 junior male athletes aged 15-17 years, conducted in Yogyakarta, Indonesia. Data collection involved measurement tests using specific instruments. The reactive agility of the athletes was assessed using a table tennis reactive agility measuring instrument, which has a content validity of greater than 0.76 [19]. Aerobic endurance was measured using the Multistage Fitness Test, an instrument commonly utilized across various sports [20].

Research Design

This study utilized a pre-experimental design, specifically a One-Group Pretest-Posttest Design. Initially, participants underwent a pre-test before any intervention. Following this, they engaged in a six-week circuit-based training program designed to enhance both reactive agility and aerobic endurance. The efficacy of the treatment was assessed by comparing the post-test results with the pre-test results, allowing for an evaluation of improvements.

Protocol Design

The experimental protocol called for the group to train three times a week (on Tuesdays, Thursdays, and Fridays) over a six-week period. Each training session began with a warm-up, followed by a core workout comprising eight circuit training stations. Participants spent 15 seconds on each exercise with a 30-second rest period between exercises and a 180-second rest interval between sets. Each session concluded with a cooldown. The regimen was consistently applied throughout the study period to ensure systematic exposure to the exercises. Table 1 presents a detailed breakdown of the training protocol and session components used in the study.

Table 1 outlines the progressive training schedule implemented over a six-week period, detailing the exercises performed in each of the 18 sessions. The first two weeks involved three sets of eight exercises, including reactive ball, reactive and jump, sit-ups, shadow and sidestep, reactive step, push-ups, jump and sidestep, and reactive shadow, each for 15 seconds with a 30-second rest between repetitions and a longer 180-second rest between circuits. The frequency of the sessions was consistent at three times per week with a medium intensity level. As the program advanced into weeks 3 to 4, and then 5 to 6, the structure remained the same, but the number of sets increased to four in the final phase to further challenge the athletes and enhance their physical capabilities.

Statistical Analysis

The statistical analysis in this study utilized the Shapiro-Wilk test to assess the normality of the data. To compare the mean differences between two variables within the sample group, a paired sample t-test was employed. This test specifically calculated the differences between the paired variables for each case [21]. Additionally, it was used to determine whether significant differences exist in the variables of the test group before and after the intervention. A difference was considered statistically significant if the p-value was less than 0.05 ($p < 0.05$), as analyzed using the SPSS 25 software at a significance level of 5%.

Results

The effectiveness of the circuit training program was analyzed using a paired sample t-test. The

Table 1. Circuit Exercise Program

Week	Meeting	Activity Type		Frequency Training
1-2	1-6	1	Reactive ball	Frequency: 3 Intensity: Medium Set: 3 Time on: 15 second Rest reps: 30 seconds Rest between circuits 180 second
		2	Reactive and jump	
		3	Sit-ups	
		4	Shadow and sidestep	
		5	Reactive step	
		6	Push-ups	
		7	Jump and sidestep	
		8	Reactive shadow	
3-4	7-12	1	Reactive ball	Frequency: 3 Intensity: Medium Set: 3 Time on: 15 second Rest reps: 30 seconds Rest between circuits 180 second
		2	Reactive and jump	
		3	Sit-ups	
		4	Shadow and sidestep	
		5	Reactive step	
		6	Push-ups	
		7	Jump and sidestep	
		8	Reactive shadow	
5-6	13-18	1	Reactive ball	Frequency: 3 Intensity: Medium Set: 4 Time on: 15 second Rest reps: 30 seconds Rest between circuits 180 second
		2	Reactive and jump	
		3	Sit-ups	
		4	Shadow and sidestep	
		5	Reactive step	
		6	Push-ups	
		7	Jump and sidestep	
		8	Reactive shadow	

mean scores for reactive agility (RA) and aerobic endurance were recorded before and after the intervention (fig. 1).

Table 2 provides a detailed overview of the normality test results for reactive agility and aerobic endurance at both pre-test and post-test stages.

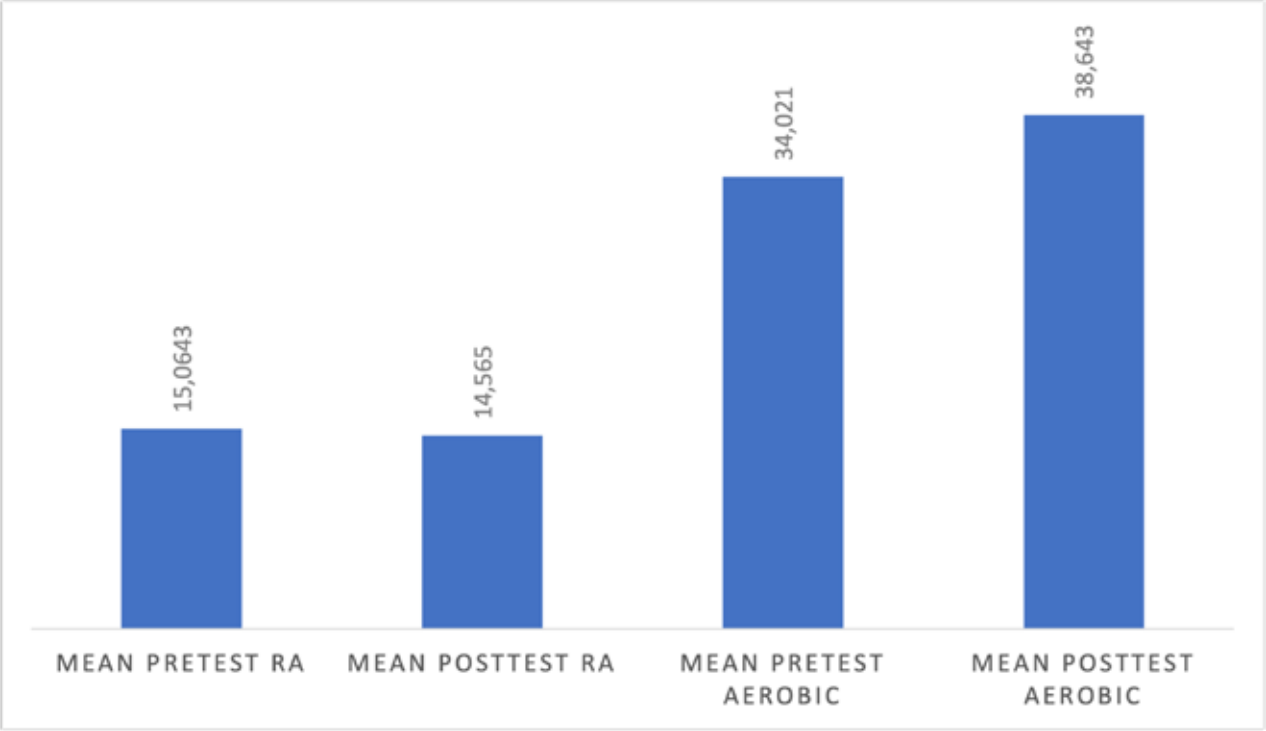
Following the table 2, the normality test results indicate that the Sig. Values for both reactive agility and aerobic endurance in the pre-tests and post-tests are greater than 0.05, suggesting that the data are normally distributed. As a result, proceeding with the paired sample t-test to evaluate the effects of the circuit training program was deemed appropriate.

Table 3 presents the paired sample test results for reactive agility and aerobic endurance, showing significant changes before and after the circuit training program.

Following the data presented in Table 3, the hypothesis tests were conducted using t-test analysis. The significant values obtained (Sig. 0.000) for both the reactive agility and aerobic endurance tests suggest significant improvements. These results indicate that the average scores for reactive agility and aerobic endurance of the junior male table tennis athletes were significantly different after undergoing the circuit training program compared to before it commenced. This demonstrates a notable improvement in their physical capabilities.

Discussion

The primary aim of this study was to determine the effects of circuit training on the reactive agility and aerobic abilities of junior table tennis athletes. The results indicated significant improvements in both reactive agility and aerobic abilities, with statistical significance observed ($p < 0.05$), before and after the implementation of the exercise regimen. These findings are consistent with previous research, underscoring the efficacy of circuit training in enhancing physical fitness. For instance, Umar [22] reported that circuit training for



MEAN PRETEST RA – average reactive agility score before the training.
MEAN POSTTEST RA – average reactive agility score after the training.
MEAN PRETEST AEROBIC – average aerobic endurance score before the training.
MEAN POSTTEST AEROBIC – average aerobic endurance score after the training.

Figure 1. Descriptive Data

Table 2. Reactive Agility Normality Test Results and Aerobic Test

Group	Variable	n	Sig	Information
Pre-test	Reactive agility	14	0.392	Usual
Pre-test	Aerobic	14	0.218	Usual
Post-test	Reactive agility	14	0.135	Usual
Post-test	Aerobic	14	0.923	Usual

Table 3. Paired Sample Test Results of Reactive Agility and Aerobic Tests

Variable		Mean	Std. Deviation	Sig.
Pair 1	Pretest Reactive Agility	15.06	0.39591	0.000
	Posttest Reactive Agility	14.56		
Pair 2	Pretest Aerobic	34.26	2.40166	0.000
	Posttest Aerobic	38.64		

four to six weeks can significantly improve physical abilities. Similarly, Bhat [23] noted substantial enhancements in athletes' agility following circuit training. Furthermore, Sonchan [11] conducted an eight-week circuit training program, involving three sessions per week with eight stations, which also demonstrated notable improvements in both agility and aerobic performance of athletes.

Specifically, the findings of this study focus on enhancing both the reactive agility and aerobic abilities of table tennis athletes, which distinguishes this research from previous studies that primarily address general agility improvements [23]. The innovative aspect of this study lies in the use of an eight-station circuit training model, which specifically targets reactive agility training. This approach not only improves reactive agility but also significantly enhances the aerobic capacity of the athletes.

Reactive agility is defined as the ability of an athlete to quickly respond to stimuli and change direction without losing balance [24]. This capability is crucial for table tennis athletes, enabling them to effectively respond to opponent's shots and execute their own strikes. In practical terms, athletes must maintain continuous movement, manage fatigue,

and recover swiftly. These requirements underscore the importance of aerobic capacity, which not only supports sustained performance in practice and competition but also helps athletes improve their skills during training sessions. Consequently, aerobic ability is a dominant aspect that enables athletes to perform at their best without succumbing to fatigue.

Exercises designed to enhance reactive agility must incorporate components of agility, the speed of direction change, and stimulus-response mechanisms. This perspective is supported by Pojskic et al. [25], who highlight the importance of direction change when athletes react to external stimuli. Furthermore, aerobic abilities can be developed through various methods, including interval and circuit training [10]. Circuit training is particularly recommended across many sports due to its effectiveness in improving physical components [17, 26]. Additionally, the specificity of physical training in sports is crucial; research conducted by Latorre et al. and Tanyeri [27, 28] demonstrates the application of physical training that aligns the characteristics of specific sports with essential physical components like reactive agility and aerobic capacity. Therefore, tailoring training to the specific characteristics of table tennis, by integrating circuit training methods that combine both reactive agility and aerobic components, is crucial for enhancing athletes' performance.

The results of the circuit training program developed in this study have successfully enhanced the reactive agility and aerobic capacity of table tennis athletes. These findings provide valuable guidance for coaches and athletes, particularly in table tennis, by demonstrating the effectiveness of circuit training methods. Such methods, which incorporate intervals of activity and rest focused on reactive agility and sustained aerobic exercise, can significantly improve performance in these areas.

A limitation of this study is its exclusive focus on male junior athletes. Future research should aim to diversify the participant pool to include different age groups and female athletes, thereby broadening the applicability and generalizability of the training methods evaluated. Additionally, exploring the impact of these methods on athletes from various sports could provide valuable insights into their effectiveness across different athletic disciplines.

Conclusions

The conclusion of this study is that training using the circuit method significantly improves reactive agility and aerobic abilities, as evidenced by a p-value of less than 0.05. These findings suggest that coaches may consider incorporating circuit training into their programs to enhance the reactive agility and aerobic capabilities of table tennis athletes, thereby achieving more effective training outcomes. Additionally, this research provides a foundation for future studies, encouraging researchers to extend these findings by exploring diverse populations and samples.

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ORIGINAL ARTICLE

An analysis of sprint kinematics: the effects of step distance, contact and flight time on sprint performance

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Abstract

Background and Study Aim Sprinting performance is crucial in many sports, and even marginal improvements in sprint mechanics can provide significant competitive advantages. The aim of this study is to examine the influence of step distance, contact time, and flight time on sprint speed.

Material and Methods The study was conducted on 26 athletes (20 males and 6 females). Body composition was measured using a bioimpedance analysis device. Sprint kinematics (step distance, contact time, and flight time) and sprint speed parameters were assessed using an optical measurement system during a 30-meter sprint test. Multiple linear regression analysis was employed to determine the effects of sprint kinematic parameters on sprint speed, as well as the effects of body composition parameters on sprint kinematics and speed. The linear regression models included one dependent variable and three independent variables.

Results Linear regression analysis revealed that step distance, contact time, and flight time were significant predictors of sprint speed, with the exception of the first step of sprint running ($p < 0.05$). Furthermore, the effects of body composition parameters (age, body weight, and height) on sprint kinematics and speed were found to be significant ($p < 0.05$). The proportions of variance explained by body composition parameters were highest for step distance and sprint speed, with R^2 values of 0.719 and 0.686, respectively.

Conclusions This study confirms that step distance, contact time, and flight time are significant predictors of sprint speed. Additionally, the results underscore the substantial influence of body composition parameters such as age, body weight, and height on sprint kinematics and speed. These findings highlight the importance of considering both kinematic and physiological factors in the training and development of athletes for optimized sprint performance.

Keywords: sprint running, sprint kinematics, sprint speed, contact time, flight time.

Introduction

Explosive activities such as jumping and sprinting are frequently used in various sports, with sprint running being one of the most crucial activities. Speed in short-distance runs is a necessary and important element in many sports [1]. Sprint running comprises various movement parameters, namely step distance, contact time, and flight time. Contact time represents the duration between the touchdown and takeoff of the same foot, while flight time is the duration between the takeoff of one foot and the touchdown of the opposite foot [2]. Step distance refers to the horizontal distance covered during a step [2]. Explosive actions like sprinting or jumping involve a cyclic contraction of muscles, characterized by alternating eccentric (muscle lengthening) and concentric (muscle shortening) phases [3]. Therefore, understanding the kinematics of sprint running is fundamental to performance analysis in athletes. Sprint performance can be analyzed through parameters such as step distance, contact time, and flight time.

Run speed is associated with the distance covered during a sprint, which varies depending on the sport [4]. Sprint speed provides a significant advantage to athletes in sports such as athletics and soccer, where step distance is a crucial factor. Step distance, contact time, and flight time are key indicators of sprint kinematics, commonly used to analyze sprint performance in athletes. It has been reported that an increase in step distance is negatively correlated with step frequency [5]. Therefore, analyzing and determining the relationship between run speed and the parameters of step distance, contact time, and flight time can enhance our understanding of sprint performance.

The physical fitness level of athletes is often indicated by body composition [6]. Furthermore, the measurement of body composition serves as a tool to monitor the performance and training intensity of athletes [7]. Common parameters measured in

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body composition analysis include body height, body weight, body mass index, lean body mass, body fat mass, and body fat percentage. The optimal level of these parameters is crucial for athletic performance. For instance, sprint runners require minimal body fat as they need to produce maximum power in a very short time, whereas endurance runners benefit from a higher fat reserve, which serves as an energy source during prolonged runs [8]. Consequently, developing lean body mass is a primary focus of sprint training, enabling athletes to achieve maximum power output in the shortest time possible [9]. Body composition parameters are regularly monitored to assess the physical fitness of sprinters. It was also reported that a significant negative relationship exists between sprint distance and body fat percentage [10]. Understanding the relationship between body composition and sprint kinematics can be instrumental in analyzing sprint performance based on body composition parameters. Against this backdrop, the aim of this study was to examine the effects of body composition and 30-meter sprint test parameters on run speed. The hypothesis was that body composition and 30-meter sprint test parameters significantly affect sprint speed.

Materials and Methods

Participants

The study included 26 athletes (20 males and 6 females). The male participants had an average age of 18.075 ± 1.029 years, a body height of 178.005 ± 5.390 cm, a body weight of 72.500 ± 13.250 kg, and a body mass index (BMI) of 22.850 ± 3.845 kg/m². The female participants had an average age of 17.027 ± 0.523 years, a body height of 161.250 ± 6.631 cm, a body weight of 52.617 ± 6.969 kg, and a BMI of 20.183 ± 1.232 kg/m². Overall, the group had an average age of 17.833 ± 1.031 years, a body height of 174.138 ± 9.094 cm, a body weight of 67.912 ± 14.701 kg, and a BMI of 22.235 ± 3.585 kg/m². All participants were competing athletes from various athletics disciplines. The research procedures were explained to the athletes, who then provided informed consent and participated voluntarily. The study was conducted in accordance with the principles of the Helsinki Declaration.

Research Design

Body Composition Measurement

The body composition parameters measured included body height (cm), body weight (kg), body mass index (BMI, kg/m²), fat percentage (%), fat mass (kg), lean body mass (kg), and muscle mass (kg). A bioelectrical impedance analyzer (Tanita BC-418MA, Tanita Corp., Tokyo, Japan) was used to measure all parameters except for body height. Body height was measured using a stadiometer (Holtain Stadiometer®, Holtain Limited®, Crymych, UK), with participants standing barefoot and the measurement taken from the top point of the head. The bioelectrical impedance device was connected to a computer via a connecting cable. The athletes' age, birth date, and body height were entered into the device's software. The measurement protocol involved the athletes, dressed in sports attire, stepping onto the device's platform. They were instructed to grip the holding apparatus, stand still with their arms at their sides, and press the button on the apparatus during the measurement. The measured values were automatically recorded in the device's software and transferred to a data chart for analysis.

30-Meters Sprint Test

Sprint run metrics such as run speed (m/sec), distance (m), contact time (sec, t-contact), and flight time (sec, t-flight) were recorded during a 30-meter sprint test using an optical measurement system (Optojump, Microgate, Bolzano, Italy). This system comprises bars measuring 100x4x3 cm, each equipped with 96 LEDs operating at a frequency of 1000 Hz. These bars, positioned 3 millimeters above the ground and spaced 1.04 cm apart, detect the interruption of light signals between the LEDs to calculate run speed, distance, t-contact, and t-flight for each step. The system, connected to a computer via cable, records test data using its software. For the test, the system was set up on a hardwood floor in a sports hall along a 30-meter track. Athletes conducted a 10-minute warm-up consisting of free-form exercises and stretching before performing the sprint test at maximum effort. They received verbal encouragement during the test and completed two trials with a recovery break in between. The faster of the two sprints was recorded as the test duration. Due to variability in step length and frequency, each athlete completed the sprint with a different number of steps, though all completed at least eight steps. For data standardization, only the first eight steps were analyzed.

Statistical Analysis

All data were analyzed using the statistical package SPSS Version 21.0 (IBM Corp, Armonk, New York, USA). Descriptive statistics (mean, standard deviation, minimum, and maximum values) were presented for all parameters. The normality of the data was assessed using the Shapiro-Wilk test. The effects of body composition and 30-meter sprint test parameters on run speed were determined through multiple regression analysis, with each model comprising one dependent and three independent variables. The collinearity among independent variables in the regression models was evaluated using the variance inflation factor (VIF) and tolerance coefficients; it was found that VIF values were below 10 and tolerance values above

0.2, indicating no concerns of multicollinearity. The relationship between run speed and both body composition and 30-meter sprint test parameters was analyzed using Pearson's correlation coefficient. A significance level of $p<0.05$ was set for all analyses.

Results

The test results for male, female, and all athletes are presented in Tables 1, 2, and 3, respectively. For all athletes, both the speed and the distance covered in the first step of the sprint were lower compared to subsequent steps (Table 3). Notably, the contact time (t-contact) during the first step was the highest of all eight steps, while the flight time (t-flight) was shorter than in the later steps. In contrast, the eighth step exhibited the lowest values for speed, distance, and t-flight among all the steps of the sprint run.

Multiple regression analysis was used to assess the effects of test parameters (distance, t-contact, and t-flight) on speed at each step of the sprint run (Table 4). The analysis revealed that the regression models were significant for all steps except the first (Table 4, $p<0.05$). The variance explanation proportions (R^2) for the three parameters on speed were also significant for all steps except the first (Table 4, $p<0.05$). The lowest and highest R^2 values

Table 1. The descriptive values of male athletes (n=20)

Parameters			Mean ($\bar{X}$)	Standard deviation (sd)	Minimum	Maximum
Body Composition		Age (years)	18.075	1.029	16.000	20.240
		Height (cm)	178.005	5.390	169.000	187.500
		Weight (kg)	72.500	13.250	61.300	110.100
		Body mass index (kg/m^2)	22.850	3.845	18.500	34.300
		Body fat percentage (%)	12.445	7.378	3.600	29.400
		Fat mass (kg)	9.665	8.069	2.200	31.800
		Lean body mass (kg)	62.835	7.569	51.600	78.300
		Body muscle mass (kg)	59.720	7.220	49.000	74.500
30 m sprint test	1_{st} Step	run speed (m/sec)	4.973	0.352	4.115	5.620
		Distance (cm)	127.000	32.322	67.500	190.500
		t-contact (sec)	0.179	0.020	0.144	0.218
		t-flight (sec)	0.077	0.018	0.038	0.104
	2_{nd} Step	run speed (m/sec)	6.222	0.460	5.165	6.875
		Distance (cm)	265.850	22.186	216.000	302.000
		t-contact (sec)	0.146	0.016	0.127	0.192
		t-flight (sec)	0.097	0.015	0.072	0.126
	3_{rd} Step	run speed (m/sec)	7.110	0.433	6.040	7.670
		Distance (cm)	310.925	26.921	253.500	350.000
		t-contact (sec)	0.131	0.013	0.109	0.158
		t-flight (sec)	0.107	0.017	0.084	0.147
	4_{th} Step	run speed (m/sec)	7.791	0.482	6.520	8.450
		Distance (cm)	344.200	30.001	286.500	384.500
		t-contact (sec)	0.127	0.013	0.110	0.155
		t-flight (sec)	0.107	0.015	0.083	0.133
	5_{th} Step	run speed (m/sec)	8.154	0.566	6.825	9.090
		Distance (cm)	368.875	31.357	309.500	418.000
		t-contact (sec)	0.122	0.013	0.105	0.150
		t-flight (sec)	0.114	0.012	0.091	0.137
	6_{th} Step	run speed (m/sec)	8.528	0.523	7.125	9.430
		Distance (cm)	386.150	29.395	325.500	431.500
		t-contact (sec)	0.117	0.010	0.101	0.142
		t-flight (sec)	0.117	0.013	0.097	0.145
	7_{th} Step	run speed (m/sec)	8.751	0.571	7.390	9.730
		Distance (cm)	400.925	34.326	332.500	465.000
		t-contact (sec)	0.116	0.012	0.100	0.142
		t-flight (sec)	0.119	0.016	0.097	0.155
	8_{th} Step	run speed (m/sec)	8.779	0.592	7.370	10.000
		Distance (cm)	403.200	38.860	326.500	461.500
		t-contact (sec)	0.116	0.011	0.096	0.140
		t-flight (sec)	0.126	0.018	0.092	0.154
	Mean	run speed (m/sec)	7.538	0.456	6.319	8.229
		Distance (cm)	325.892	25.928	266.190	358.310
		t-contact (sec)	0.131	0.012	0.114	0.159
		t-flight (sec)	0.108	0.013	0.087	0.131

Table 2. The descriptive values of female athletes (n=6)

Parameters			Mean ($\bar{X}$)	Standard deviation (sd)	Minimum	Maximum
Body Composition		Age (years)	17.027	0.523	16.000	17.390
		Height (cm)	161.250	6.631	154.000	172.000
		Weight (kg)	52.617	6.969	46.300	65.900
		Body mass index (kg/m^2)	20.183	1.232	19.000	22.300
		Body fat percentage (%)	22.183	2.086	19.800	25.300
		Fat mass (kg)	11.750	2.588	9.200	16.700
		Lean body mass (kg)	40.867	4.554	36.700	49.200
		Body muscle mass (kg)	38.783	4.332	34.800	46.700
30 m sprint test	1_{st} Step	run speed (m/sec)	4.548	0.179	4.315	4.745
		Distance (cm)	135.167	19.374	112.500	164.500
		t-contact (sec)	0.174	0.033	0.137	0.235
		t-flight (sec)	0.082	0.022	0.045	0.107
	2_{nd} Step	run speed (m/sec)	5.705	0.152	5.485	5.955
		Distance (cm)	241.000	14.262	222.500	262.000
		t-contact (sec)	0.144	0.019	0.122	0.178
		t-flight (sec)	0.093	0.009	0.079	0.102
	3_{rd} Step	run speed (m/sec)	6.478	0.161	6.305	6.680
		Distance (cm)	276.583	10.777	261.500	292.500
		t-contact (sec)	0.135	0.018	0.116	0.169
		t-flight (sec)	0.097	0.012	0.078	0.113
	4_{th} Step	run speed (m/sec)	6.983	0.200	6.665	7.155
		Distance (cm)	305.917	9.308	294.000	320.000
		t-contact (sec)	0.128	0.015	0.108	0.152
		t-flight (sec)	0.106	0.014	0.078	0.116
	5_{th} Step	run speed (m/sec)	7.348	0.261	6.905	7.695
		Distance (cm)	327.833	8.852	316.500	343.500
		t-contact (sec)	0.124	0.013	0.109	0.147
		t-flight (sec)	0.107	0.011	0.092	0.125
	6_{th} Step	run speed (m/sec)	7.560	0.278	7.245	7.900
		Distance (cm)	341.917	9.795	328.500	354.000
		t-contact (sec)	0.119	0.014	0.103	0.142
		t-flight (sec)	0.114	0.008	0.106	0.127
	7_{th} Step	run speed (m/sec)	7.725	0.261	7.395	8.055
		Distance (cm)	351.250	13.927	332.500	369.500
		t-contact (sec)	0.118	0.011	0.104	0.136
		t-flight (sec)	0.115	0.005	0.110	0.125
	8_{th} Step	run speed (m/sec)	7.910	0.284	7.450	8.285
		Distance (cm)	359.833	13.772	342.500	380.000
		t-contact (sec)	0.116	0.013	0.101	0.136
		t-flight (sec)	0.117	0.005	0.110	0.124
	Mean	run speed (m/sec)	6.782	0.162	6.578	7.033
		Distance (cm)	292.437	8.166	279.000	301.500
		t-contact (sec)	0.132	0.017	0.112	0.162
		t-flight (sec)	0.104	0.009	0.088	0.112

were observed in the regression models for the first and seventh steps of the sprint, respectively (Table 4, R^2=0.268 and 0.941). In the regression model based on the mean values of the parameters, all independent variables (distance, t-contact, and t-flight) significantly predicted the speed parameter (Table 4, $p<0.05$). The $R^2$of this model was 0.933 (Table 4). Except for the first step and mean values, all independent variables were significant predictors of run speed across the models (Table 4, $p<0.05$). However, the t-flight parameter was not a significant predictor of run speed in the regression model for the eighth step (Table 4, $p>0.05$). Overall, the results indicate that distance, t-contact, and t-flight are significant predictors of sprint speed.

Multiple regression analysis indicated that body composition parameters (age, body height, and body weight) significantly influenced sprint run parameters (speed, distance, t-contact, and t-flight) across all models (Table 5, $p<0.05$). The highest variance explanation ratio (R^2) for the distance parameter was 0.719, showing a substantial influence by body composition (Table 5). The lowest R^2 was 0.378, observed in the model predicting the t-flight parameter with body composition parameters (Table 5). Beta (β) coefficients revealed that body height

Table 3. The descriptive values of all athletes (n=26)

Parameters			Mean ($\bar{X}$)	Standard deviation (sd)	Minimum	Maximum
Body Composition		Age (years)	17.833	1.031	16.000	20.240
		Height (cm)	174.138	9.094	154.000	187.500
		Weight (kg)	67.912	14.701	46.300	110.100
		Body mass index (kg/m^2)	22.235	3.585	18.500	34.300
		Body fat percentage (%)	14.692	7.730	3.600	29.400
		Fat mass (kg)	10.146	7.185	2.200	31.800
		Lean body mass (kg)	57.765	11.696	36.700	78.300
		Body muscle mass (kg)	54.888	11.149	34.800	74.500
30 m sprint test	1_{st} Step	run speed (m/sec)	4.875	0.366	4.115	5.620
		Distance (cm)	128.885	29.687	67.500	190.500
		t-contact (sec)	0.178	0.023	0.137	0.235
		t-flight (sec)	0.078	0.018	0.038	0.107
	2_{nd} Step	run speed (m/sec)	6.103	0.463	5.165	6.875
		Distance (cm)	260.115	22.995	216.000	302.000
		t-contact (sec)	0.145	0.016	0.122	0.192
		t-flight (sec)	0.096	0.014	0.072	0.126
	3_{rd} Step	run speed (m/sec)	6.964	0.470	6.040	7.670
		Distance (cm)	303.000	28.138	253.500	350.000
		t-contact (sec)	0.132	0.014	0.109	0.169
		t-flight (sec)	0.105	0.016	0.078	0.147
	4_{th} Step	run speed (m/sec)	7.604	0.552	6.520	8.450
		Distance (cm)	335.365	31.176	286.500	384.500
		t-contact (sec)	0.127	0.013	0.108	0.155
		t-flight (sec)	0.107	0.014	0.078	0.133
	5_{th} Step	run speed (m/sec)	7.968	0.614	6.825	9.090
		Distance (cm)	359.404	32.771	309.500	418.000
		t-contact (sec)	0.122	0.013	0.105	0.150
		t-flight (sec)	0.112	0.012	0.091	0.137
	6_{th} Step	run speed (m/sec)	8.305	0.630	7.125	9.430
		Distance (cm)	375.942	32.204	325.500	431.500
		t-contact (sec)	0.117	0.011	0.101	0.142
		t-flight (sec)	0.116	0.012	0.097	0.145
	7_{th} Step	run speed (m/sec)	8.514	0.675	7.390	9.730
		Distance (cm)	389.462	37.281	332.500	465.000
		t-contact (sec)	0.116	0.011	0.100	0.142
		t-flight (sec)	0.118	0.014	0.097	0.155
	8_{th} Step	run speed (m/sec)	8.578	0.650	7.370	10.000
		Distance (cm)	393.192	39.151	326.500	461.500
		t-contact (sec)	0.116	0.011	0.096	0.140
		t-flight (sec)	0.124	0.016	0.092	0.154
	Mean	run speed (m/sec)	7.364	0.518	6.319	8.229
		Distance (cm)	318.171	27.035	266.190	358.310
		t-contact (sec)	0.131	0.013	0.112	0.162
		t-flight (sec)	0.107	0.012	0.087	0.131

was the most influential predictor of speed and distance (Table 5, β=0.802 and 0.985, respectively). Body weight was found to be the most significant predictor for t-contact and t-flight parameters (Table 5, β=0.568 and -0.684, respectively).

Discussion

The results from the 30-meter sprint test revealed that the parameters (distance, t-contact, and t-flight) significantly influenced sprint speed at each step, with the exception of the first step (Table 4). Analysis of standardized beta coefficients showed that the effects of mean t-contact and t-flight parameters were comparable, while the mean distance had the most substantial impact on mean sprint speed (Table 4). Furthermore, sprint parameters were found to be significantly influenced by body composition parameters (age, body height, and weight) (Table 5). The variance in mean distance was most notably explained by body composition parameters, accounting for 71.9% (Table 5). Additionally, the combined body composition parameters significantly predicted mean sprint speed, explaining 68.6% of the variance (Table 5).

In the study by Talukdar et al. [11], it was

Table 4. The Effects of Distance, Contact Time (t-contact) and Flight Time (t-flight) Parameters on Run Speed in 30 m. Sprint Test

Dependent Variable: Speed	Predictor Variables	B	β	p	r (zero-order)	R^2
1_{st} step	constant	5.366		0.000#		0.268
	distance	0.006	0.469	0.018#	0.466#	
	t-contact	-4.860	-0.318	0.230	-0.191	
	t-flight	-4.672	-0.227	0.389	0.051	
	*F= 2.680; **p>0.05					
	Model: speed = 5.366+ 0.006 x distance - 4.860 x t-contact - 4.672 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
2_{nd} step	constant	5.823		0.000#		0.893
	distance	0.021	1.053	0.000#	0.718#	
	t-contact	-23.614	-0.832	0.000#	-0.471#	
	t-flight	-18.756	-0.584	0.000#	0.436#	
	*F=61.083; **p<0.05					
	Model: speed = 5.823 + 0.021 x distance - 23.614 x t-contact - 18.756 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
3_{rd} step	constant	6.891		0.000#		0.888
	distance	0.019	1.138	0.000#	0.650	
	t-contact	-25.618	-0.786	0.000#	-0.577	
	t-flight	-22.062	-0.776	0.000#	0.394	
	*F=58.218; **p<0.05					
	Model: speed = 6.891+ 0.019 x distance - 25.618 x t-contact - 22.062 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
4_{th} step	constant	6.714		0.000#		0.898
	distance	0.020	1.106	0.000#	0.778#	
	t-contact	-24.602	-0.612	0.000#	-0.415#	
	t-flight	-23.683	-0.614	0.000#	0.353#	
	*F=64.320; **p<0.05					
	Model: speed =6.714 + 0.020 x distance – 24.602 x t-contact – 23.683 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
5_{th}. step	constant	7.776		0.000#		0.933
	distance	0.021	1.131	0.000#	0.731#	
	t-contact	-27.736	-0.608	0.000#	-0.653#	
	t-flight	-35.703	-0.705	0.000#	0.414#	
	*F= 102.545; **p<0.05					
	Model: speed =7.776 + 0.021 x distance - 27.736 x t-contact - 35.703 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
6_{th} step	constant	7.285		0.000#		0.930
	distance	0.020	1.028	0.000#	0.765#	
	t-contact	-33.587	-0.586	0.000#	-0.518#	
	t-flight	-22.539	-0.464	0.000#	0.345#	
	*F=97.426; **p<0.05					
	Model: speed =7.285 + 0.020 x distance – 33.587 x t-contact - 22.539 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
7_{th} step	constant	7.373		0.000#		0.941
	distance	0.022	1.193	0.000#	0.716#	
	t-contact	-29.241	-0.538	0.000#	-0.581#	
	t-flight	-33.076	-0.670	0.000#	0.337#	
	*F=117.755; **p<0.05					
	Model: speed =7.373+ 0.022 x distance - 29.241 x t-contact - 33.076 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
8_{th} step	constant	7.686		0.000#		0.694
	distance	0.016	0.938	0.000#	0.607#	
	t-contact	-27.963	-0.525	0.000#	-0.481#	
	t-flight	-15.807	-0.388	0.051	0.330	
	*F=16.598; **p<0.05					
	Model: speed = 7.686+ 0.016 x distance - 27.963 x t-contact - 15.807 x t-flight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
Mean speed	constant	5.852		0.000#		0.933
	mean distance	0.023	1.198	0.000#	0.774#	
	mean t-contact	-24.301	-0.644	0.000#	-0.461#	
	mean t-flight	-24.335	-0.601	0.000#	0.484#	
	*F=101.768; **p<0.05					
	Model: speed = 5.852+ 0.023 x distance - 24.301 x t-contact – 24.335 x t-flight					

- p<0.05, * - Coefficient of regression model, ** - significance value of regression model, t-contact: contact time, t-flight: flight time.

Table 5. The Effects of Body Composition Parameters on Run Speed. Distance. Contact Time (t-contact) and Flight Time (t-flight) Parameters in 30 m. Sprint Test

	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
Dependent Variable: Mean Speed	constant	-2.750		0.077		0.686
	age	0.202	0.402	0.006#	0.603#	
	height	0.046	0.802	0.000#	0.564#	
	weight	-0.021	-0.609	0.001#	0.013	
	*F= 16.030; **p<0.05					
	Model: speed = -2.750+ 0.202 x age + 0.046 x height - 0.021 x weight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
Dependent Variable: Mean distance	constant	-220.892		0.006#		0.719
	age	5.277	0.201	0.122	0.498#	
	height	2.929	0.985	0.000#	0.722#	
	weight	-0.960	-0.522	0.002#	0.179	
	*F=18.735; **p<0.05					
	Model: distance = -220.892+ 5.277 x age + 2.929 x height - 0.960 x weight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
Dependent Variable: Mean t-contact	constant	0.184		0.002#		0.466
	age	-0.006	-0.470	0.012#	-0.308	
	height	0.000	0.089	0.696	0.270	
	weight	0.001	0.568	0.013#	0.524#	
	*F=6.409; **p<0.05					
	Model: t-contact = 0.184 - 0.006 x age + 0.000 x height + 0.001 x weight					
	Predictor Variables	**B**	**β**	**p**	**r (zero-order)**	**R^2**
Dependent Variable: Mean t-flight	constant	-0.053		0.312		0.378
	age	0.002	0.176	0.354	0.302	
	height	0.001	0.660	0.013#	0.279	
	weight	-0.001	-0.684	0.006#	-0.205	
	*F=4.451; **p<0.05					
	Model: t-flight = -0.053 + 0.002 x age + 0.001 x height – 0.001 x weight					

- p<0.05. * - Coefficient of regression model. ** - significance value of regression model. t-contact: contact time. t-flight: flight time.

determined that the t-contact value significantly impacted 15-meter sprint speed in adolescent female athletes, but it was not identified as a significant predictor of 30-meter sprint speed. In our study, t-contact values were found to significantly predict 30-meter sprint speed, except for the first step of the run (Table 4). While Talukdar et al. focused on adolescent female athletes, our study was conducted on young athletes. Therefore, the disparity in the 30-meter sprint findings may be attributed to the age difference between the two research groups.

Another study reported significant predictions regarding t-contact values in the 0-5 meter range for sprint speed between 5 to 10 meters, along with a positive correlation between t-flight values in the 0-5 meter range and sprint speed in both 0-5 and 0-10 meters [12]. Additionally, a significant and positive correlation was found between t-flight values in the 0-10 meter range and sprint speed in the 0-5 meter range in this study. The aforementioned study utilized a 10-meter sprint test, whereas our study involved a 30-meter sprint test. Despite the difference in sprint distances between the two studies, our findings align closely with those reported in the aforementioned study.

In a study involving female physical education students, it was observed that the post-test t-contact values in the resisted sprint training group were higher than their pre-test values [13]. However, the decrease in post-test t-flight values compared to the pre-test values was not statistically significant in the mentioned study. The increase in t-contact value suggests an enhanced step frequency during sprint running due to the effects of resisted training. Consequently, the increase in step frequency during sprint running may lead to lower t-flight values.

The mentioned study also found that the post-test running speed values of both the resisted and standard training groups were significantly better than their pre-test values. Furthermore, a correlation was observed between sprint speed and t-contact and t-flight values in the mentioned study. Our results coincide with these findings, further substantiating the impact of t-contact and t-flight dynamics on improving sprint performance across different training modalities.

Makaruk et al. [14] found that the 20-meter sprint speed increased and the t-contact value decreased after assisted and free sprint training periods in female college students. The decrease in t-contact value may be related to step distance in the mentioned study. Longer step distances may result in less t-contact time. The increase in post-test sprint speed supports this assumption. The findings of our study were parallel to the results obtained in the mentioned study.

Spinks et al. [15] determined a significant decrease in right foot t-contact values after weighted and unweighted training periods in terms of 0-15 meters acceleration performance. This finding suggests that sprint trainings might help improve t-contact values during sprint running. Additionally, it was indicated that the use of additional weights might lead to a decrease in t-flight values and an increase in t-contact values during sprint running. Lockie et al. [16] observed a decrease in t-flight values and an increase in t-contact values during the first and second steps of a 15-meter sprint, when weighted with 32.2% of body weight, compared to unweighted conditions. Clark et al. [17] found a 5.2% decrease in t-contact values and a 3.4% increase in t-flight values in a 60-meter assisted sprint test, compared to unassisted test conditions. The use of extra weights during sprint running increases the intensity of exercise, thereby potentially improving sprint performance in subsequent unweighted runs. Our results support these findings, showing improved sprint performance and optimized t-contact and t-flight values following training sessions that incorporated various resistance levels.

In a study conducted by Mackala et al. [18], there was no significant difference between groups in terms of t-contact values, while t-flight values were higher in elite sprinters compared to sub-elite sprinters. This suggests that t-flight values are crucial determinants of sprint performance. Similarly, in our study, t-flight values were a significant predictor of sprint speed, indicating that longer t-flight times may be associated with higher sprint performance.

Body composition also influences physical performance. Attributes such as age, body height, and weight are closely linked to sprint performance. Meyers et al. [19] found a correlation between age and 30-meter sprint speed, and noted that body weight negatively impacted sprint speed. Our findings echo these results. A higher body weight demands more energy for movement, thus, a higher body weight is typically associated with slower sprint speeds. Additionally, our study found that body weight negatively affected both t-flight and distance values (Table 5), underscoring the importance of optimal body weight for enhancing sprint performance.

In summary, our findings align with existing research showing that t-flight values are critical determinants of sprint performance and that body composition significantly influences sprint speed. Specifically, increased body weight has been consistently linked to decreased sprint performance due to higher energy demands. Future research could further explore the specific biomechanical changes that occur with variations in body weight and how these affect different components of sprint performance. Additionally, investigating the effects of targeted training interventions on sprint kinematics in athletes of varying body compositions could provide deeper insights into optimizing sprint techniques for enhanced athletic outcomes.

Conclusions

This study illustrates that the t-contact, t-flight, and distance parameters influence sprint performance. However, it was observed that the t-contact and t-flight parameters did not affect sprint speed during the initial step of running. The acceleration phase of sprint running may modify how t-contact and t-flight parameters impact sprint speed. Furthermore, regression models indicated that body composition parameters have a more pronounced effect on the mean speed and distance values in sprinting compared to the t-contact and t-flight parameters. Variables such as age, body weight, and height appear to significantly influence sprint performance. Consequently, it is advisable to tailor sprint training programs to align with an athlete's specific body composition. Future studies should investigate the impact of various body composition parameters on sprint performance. Additionally, the insights gained on the influence of distance, t-contact, and t-flight on sprint performance can serve as a foundation for trainers to develop more effective training programs, potentially enhancing athlete sprint performance based on these findings.

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ORIGINAL ARTICLE

Effects of thoracic spine mobilization on chest expansion in patients with chronic mechanical neck pain: a randomized controlled trial

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Author's contribution; A-Study design; B- Data collection; C- Statistical analysis; D- Manuscript Preparation; E- Fundus Collection

Abstract

Background and Study Aim Chronic mechanical neck pain significantly impacts the quality of life and functional capacity of individuals, often necessitating long-term management strategies. Traditional stretching exercises are commonly prescribed, but their effectiveness compared to other interventions remains underexplored. The objective of this study was to compare the effectiveness of traditional stretching exercise regimens against thoracic spine and rib mobilization in patients with chronic mechanical neck pain.

Material and Methods This randomized controlled trial included 30 patients aged between thirty and fifty years, all suffering from mechanical neck pain. Patients were randomly assigned to one of two groups, with 15 in each group (Group A: n=15; Group B: n=15). Group A received thoracic spine mobilization coupled with standard passive stretching exercises, whereas Group B underwent a traditional stretching exercise regimen. Both groups were evaluated using the visual analogy scale for pain, active cervical range of motion (ROM), and chest expansion, both before and after a two-week therapy course.

Results Findings from this study were analyzed using a two-way mixed-model multivariate analysis of variance (MANOVA). The results showed no significant differences between Group A (thoracic spine mobilization and standard passive stretching) and Group B (traditional stretching regimen) regarding pain intensity, active cervical range of motion, and chest expansion after the two-week intervention period ($p > 0.05$). However, significant improvements were observed within each group across all measured outcomes, including reductions in pain intensity and increases in cervical range of motion and chest expansion ($p < 0.001$).

Conclusions The study confirms that both passive stretching exercises and thoracic spine mobilization are beneficial interventions for enhancing physical outcomes in patients with mechanical nonspecific neck pain. These approaches are equally effective in improving overall physical functionality, underscoring their value in therapeutic settings for neck pain management.

Keywords: conventional stretching, exercise regimes, thoracic and rib mobility, chronic mechanical neck pain

Introduction

Chronic mechanical nonspecific neck pain is a prevalent condition that disrupts the daily lives of many, especially in middle-aged populations. Its impact on health and productivity highlights the need for innovative and effective management approaches. Among middle-aged individuals, the onset of neck pain is notably high, underscoring the urgent necessity for targeted therapeutic strategies [1]. Various biomechanical factors contribute to this condition, including sensitivities in the cervical spine's ligaments, muscles, zygapophyseal joints, intervertebral discs, and neural tissues [2]. Mechanical dysfunctions in the thoracic or cervical regions can also restrict neck mobility, further exacerbating nonspecific neck pain, while altered functioning of muscles or joints intensifies this ailment [3]. Understanding these diverse biomechanical factors is crucial for developing

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effective treatments. Consequently, accurate diagnosis and management require a comprehensive evaluation, encompassing a detailed medical history, physical examination, and imaging studies to ensure appropriate interventions [2, 3].

Therefore, addressing these multifaceted biomechanical contributors through refined diagnostic and therapeutic approaches is essential. This focus forms the basis for exploring more targeted interventions that could potentially mitigate the adverse effects of chronic mechanical nonspecific neck pain.

The cervical, thoracic, and lumbar spines are strongly interrelated due to their close anatomical and biomechanical links [3]. The thoracic spine, in particular, plays a crucial role in supporting the cervical spine and significantly influences its kinematics [4]. Postural dysfunction of the thoracic spine is recognized as a predisposing factor for cervical spine dysfunction due to impaired mechanical loading [3, 6]. Concurrent motion of the thoracic spine is necessary to facilitate the full range of motion in the cervical spine. Specifically, the upper thoracic spine (T1-T6) contributes approximately 10% to cervical rotation, 25% to cervical flexion/extension, and 14% to cervical lateral flexion [4, 5]. However, limited segmental mobility or postural malalignment of the thoracic spine may restrict cervical spine movement [4, 7]. Additionally, thoracic spine postural impairments can lead to muscle dysfunction around the cervical region, affecting the function of the trapezius, scalene, sternocleidomastoid, levator scapulae, and serratus anterior muscles [8]. Thoracic hyperkyphosis is thought to contribute to the increased prevalence of cervical spine and shoulder joint dysfunctions in older adults [5].

This comprehensive understanding of the interrelations between the thoracic and cervical spine underscores the necessity of addressing thoracic postural dysfunctions in treatments aimed at alleviating neck pain. By focusing on thoracic mobility and alignment, therapeutic strategies may more effectively manage mechanical neck pain, particularly in populations vulnerable to degenerative changes.

Recent research suggests that improved thoracic kinematics can significantly influence cervical spine function, thereby making thoracic spine mobilization a promising treatment for chronic mechanical nonspecific neck pain [9]. Both thoracic thrust and nonthrust mobilizations have demonstrated beneficial effects in alleviating symptoms associated with nonspecific neck pain, such as reduced pain intensity, increased range of motion, and decreased self-reported disability [9, 10, 11]. Although previous studies have explored the effects of thoracic mobilization on neck pain, there is a notable gap in research examining the combined effects of rib mobilization and traditional stretching exercises, particularly over a two-week period. This gap underscores the need for further studies to assess the impact of such combined interventions on neck pain. Addressing this need will not only contribute to the existing body of knowledge on effective pain management strategies but also enhance understanding of the benefits derived from integrating mobilization and stretching exercises. Consequently, this study aims to evaluate the efficacy of combining traditional stretching exercise training with rib and thoracic spine mobilization in patients suffering from persistent mechanical nonspecific neck pain.

Materials and Methods

Participants

A total of thirty patients, including both males and females, referred by an orthopedic specialist for chronic mechanical nonspecific neck pain (MNP), participated in this study. Eligibility criteria included individuals aged 30 to 50 who had been experiencing neck pain for at least three months. Exclusion criteria were neurological diseases, vertebral fractures, rheumatic disorders, inflammatory or osteo-metabolic diseases, or a history of surgical spinal fixation. After obtaining informed consent, participants were randomly assigned into two groups.

Research Design

This randomized controlled study assessed the efficacy of integrating thoracic and rib mobilization with traditional stretching exercises for treating chronic mechanical nonspecific neck pain. The study was carried out at the Ababa Private Physical Therapy Center in Beni-surf, Egypt, over a period of six months, from January 01, 2021, to June 10, 2021. Participants were randomly divided using index cards into two groups of 15, with a total of 30 index cards used for the random assignment. Group A received both thoracic spine and rib mobilization along with conventional passive stretching exercises, while Group B was treated with a conventional passive stretching exercise program alone. The ethical committee approved the study protocol with reference number P.T.REC/012/003379, conducted in accordance with the 1964 Helsinki Declaration. For visual reference, see Figure 1, which presents a flow diagram illustrating the selection process of participants.

Assessment procedures

Initially, a comprehensive patient history was collected, which included inquiries about the patient's age, sex, occupation, onset, duration, nature, and location of symptoms, as well as the mechanism of injury and activities that might exacerbate or alleviate pain. This was followed by a thorough physical examination. The pre-and post-

treatment assessments included:

1. *Visual Analog Scale (VAS).* This employs a 100 mm horizontal line to gauge pain levels at rest, with 0 indicating no pain and 100 representing the highest level of discomfort. Patients were asked to mark the point that corresponded to their current level of pain.
2. *Cervical Active Range of Motion (CAROM).* Measurement was conducted using a tape measure. Patients performed movements in various directions, including flexion, extension, lateral bending (left and right), and rotation (left and right). Measurements were taken three times, and the average for each direction was calculated.
3. *Chest Expansion.* Measurements of upper, middle, and lower chest expansion were performed with the patient seated. Patients were instructed to fully inspire and expire. Measurements were taken at the peak of deep inspiration and the end of full expiration, and the difference was calculated. Measurements were repeated twice, and the average was computed for each level (upper, middle, and lower).

All data were meticulously recorded on an evaluation sheet during the patient's initial or pre-treatment visit to the clinic.

Interventions

Participants in the study were assigned to specific treatment programs with strict instructions to avoid combining these with any pharmacological or other physical treatments.

Group A - Mobilization Techniques:

- *Flexion Mobilization.* Patients sat with hands behind their heads, curling elbows into their groin to induce thoracic flexion. The therapist applied overpressure in cranial and horizontal directions.
- *Extension Mobilization.* From the same starting position as flexion, patients placed one or both feet on a chair to flex the lumbar spine. As patients lifted their elbows upward, the therapist applied overpressure in the direction of thoracic extension.
- *Lateral Flexion Mobilization.* Patients sat with hands behind their heads, directing elbows away from their bodies. During this, the therapist positioned themselves to apply targeted pressure to facilitate lateral flexion.
- *Rotation Mobilization.* Patients sat with arms folded. The therapist, positioned to the side of the patient, facilitated rotation by applying overpressure towards the scapula and pectoral areas, enhancing thoracic mobility.

Group B - Stretching Exercise Program:

This group underwent a passive stretching program targeting the inhibition and elongation of over-activated neck muscles such as the sternocleidomastoid, cervical extensors, suboccipital muscles, levator scapulae, and upper trapezius. Treatments were delivered face-to-face, with three weekly sessions of 45 minutes each. Each stretching exercise was held for 30 seconds and repeated four to five times in a clinical setting, strictly isolated from any other treatments.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software for Windows, version 25.0. Descriptive statistics, including means, standard deviations, and percentages, were computed for each group both at baseline and after the two-week intervention period. The Chi-square test was utilized to analyze the gender distribution among groups. For comparing the total mean change scores for pain intensity, cervical range of motion, and chest expansion over time, a two-way multivariate analysis of variance (MANOVA) using mixed models was employed. Wilks' lambda was used to calculate the F value for the overall model fit. When MANOVA revealed significant effects ($P < 0.05$), follow-up univariate ANOVAs were performed with Bonferroni adjustments to the p-values to safeguard against Type I errors.

Results

Table 1 confirms that at baseline, there were no statistically significant differences between the groups in terms of age, weight, height, or gender ($P>0.05$), indicating that the groups were well-matched at the study's commencement.

A mixed-design multivariate analysis was conducted to evaluate the differences between the groups in the combined mean change scores of cervical range of motion, chest expansion, and pain outcome measures. The main effects of the groups showed no statistically significant multivariate effect [Wilk's Lambda = 0.51, $F(20,66) = 1.3$, $P = 0.21$, $h^2 = 0.28$]. However, statistically significant multivariate effects were indicated by the interaction between groups and time [Wilk's Lambda = 0.06, $F(20,66) = 10.43$, $P < 0.001$, $h^2 = 0.76$].

Subsequent univariate ANOVAs revealed a significant change in the visual analogy scale (VAS) for pain intensity: $P < 0.001$, $F(2,42) = 10.68$. The proper rotation range of motion (ROM) outcome showed no significant change [$F(2,42) = 0.001$, $P = 0.99$, $h^2 = 0.001$], and there was no significant change in the left rotation ROM outcome. The flexion ROM outcome also showed no significant change, $F(2,42) = 2.01$, $P = 0.15$, $h^2 = 0.05$.

After two weeks of intervention, there were no statistically significant differences between the groups concerning pain intensity, cervical range of motion, or chest expansion outcomes ($P > 0.05$) as detailed in Tables 2 and 3.

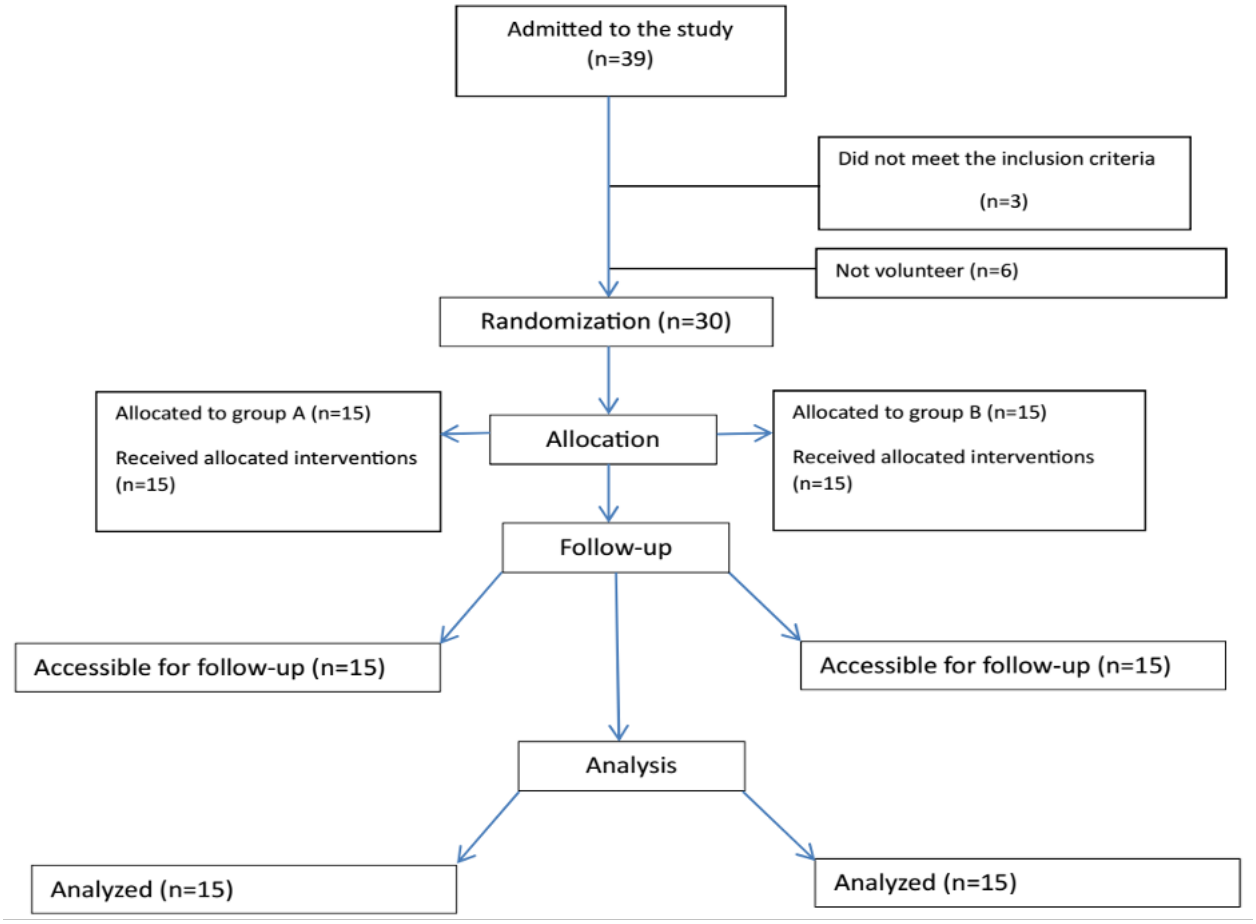

Figure 1. Flow diagram showing participants' selection

Table 1. General characteristics of the patients in the two groups (A&B)

Characteristics	Group A (n=15)	Group B (n=15)	F-Value	P-Value
Age(years)	38.3±11.0	39.4±9.98	0.1	0.9
Weight(kg)	77.67±10.44	78.2±8.12	0.06	0.94
Height(cm)	167.1±5.06	168.8±4.95	0.87	0.43
Sex, n(%)				
Male	5(33.3%)	6(40%)	X2=0.57	0.76
Female	10(66.7%)	9(60%)		
VAS (mm)	76.67±9.76	74.67±11.87	0.16	0.85
Flex (cm)	9.93±3.95	8.8±3.12	0.52	0.6
Ext.(cm)	15.8±1.61	14.47±2.75	1.2	0.31
RLF (cm)	14.47±3.83	14.6±3.66	0.14	0.87
LLF (cm)	14.67±3.02	14.47±3.6	1.14	0.33
RR (cm)	15.27±2.34	15.2±2.73	1.98	0.15
LR (cm)	16.27±2.52	15.8±2.91	2.36	0.11
L. Chest(cm)	1.6±0.51	1.8±0.68	0.51	0.6
Up. Chest(cm)	1.87±0.64	1.6±0.63	0.79	0.46
M. Chest(cm)	1.27±0.46	1.53±0.64	1.6	0.21

Visual Analogue Scale (VAS); Flex (Flexion); Extension (Ext); Right Rotation (RR); Left Rotation (LR); Right Lateral Flexion (RLF); Left Lateral Flexion (LLF); Lower (L); Upper (Up); Medium (M); Mean Difference (MD); Confidence Interval (CI); Probability Value (p). * Data are mean± SD; * P-Value < 0.05 indicates statistical significance.

Table 2. Clinical Characteristics of Subjects following a Two-Week Intervention (N=30*)

Characteristics	Group I ((n=15)	Group II (n=15)	F-Value	P-Value
VAS (mm)	41.13±14.07	41.0±11.46	10.68	0.0002
Flex (cm)	7.53±3.14	6.47±2.67	2.01	0.15
Ext.(cm)	12.67±1.76	11.87±2.61	2.27	0.12
RLF (cm)	11.67±3.2	11.8±3.17	0.74	0.48
LLF (cm)	11.73±2.58	11.6±2.67	0.12	0.89
RR (cm)	12.27±2.71	12.27±3.28	0.001	0.99
LR (cm)	12.87±2.8	12.2±2.88	0.25	0.78
L. Chest (cm)	2.6±0.51	2.8±0.68	10.48	0.0002
Up. Chest (cm)	2.93±0.7	2.67±0.72	3.62	0.04
M. Chest (cm)	2.2±0.56	2.47±0.52	5.98	0.005

VAS, Visual Analogue Scale; Flex, Flexion; Ext, Extension; RR, Right Rotation; LR, Left Rotation; RLF, Right Left Lateral Flexion (LLF); L stands for lower; Up for upper; M for medium; MD for mean difference; CI for confidence interval; and p for probability value. * P-Value < 0.05 indicates statistical significance; mean ± standard deviation is presented. * P-Value < 0.05 indicates statistical significance; mean ± standard deviation is presented.

Table 3. Between Groups Effects after two weeks of intervention

Outcomes	GI Versus G2		Partial Eta Squared
	MD (95% CI)	P-Value	
VAS (mm)	-0.07 (-1.09, 0.95)	0.99	0.34
Flex (cm)	1.13 (-1.78, 4.04)	0.99	0.09
Ext.(cm)	0.8 (-1.47, 3.07)	0.99	0.1
RLF (cm)	-0.13 (-3.14, 2.87)	0.99	0.03
LLF (cm)	0.13 (-2.35, 2.62)	0.99	0.01
RR (cm)	0.01 (-2.83, 2.83)	0.99	0.001
LR (cm)	0.67 (-2.03, 3.36)	0.99	0.01
L. Chest (cm)	-0.2 (-0.82, 0.42)	0.99	0.33
Up. Chest (cm)	0.27 (-0.36, 0.89)	0.87	0.15
M. Chest (cm)	-0.27 (-0.75, 00.22)	0.53	0.22

VAS, Visual Analogue Scale; Flex, Flexion; Ext, Extension; RR, Right Rotation; LR, Left Rotation; RLF, Right Left Lateral Flexion (LLF); L stands for lower; Up for upper; M for medium; MD for mean difference; CI for confidence interval; and p for probability value. * P-Value < 0.05 indicates statistical significance; mean ± standard deviation is presented. * P-Value < 0.05 indicates statistical significance; mean ± standard deviation is presented.

However, after two weeks of treatment in each group, there were statistically significant differences in all outcome measures ($p<0.01$), as shown in Table 4 comparing groups.

Discussion

This study aimed to compare the effects of thoracic mobilization versus a routine regimen of stretching exercises on individuals with chronic mechanical nonspecific neck pain, focusing on chest expansion and active cervical range of motion. Although significant improvements were observed within both groups in terms of pain intensity, cervical range of motion, and chest expansion, no significant differences were found between the groups after two weeks of intervention. This suggests that while both interventions are effective in improving the measured outcomes, one is not superior to the other in the short-term context of this study.

Previous studies have primarily focused on the effects of thoracic mobilization on neck pain. For instance, research has shown that thoracic spine mobilization can significantly reduce pain and improve function in patients with neck pain [10, 13]. However, the combined effects of rib mobilization

Table 4. Within-group changes after two weeks of intervention

Variables	Group A (n=15)		Group B (n=15)	
	Change from baseline to 2 weeks		Change from baseline to 2 weeks	
	MD (95% CI)	P-Value	MD (95% CI)	P-Value
VAS (mm)	35.33(28.82, 41.85)	0.0001	32.67(26.15, 39.18)	0.0001
Flex (cm)	2.4(1.89, 2.91)	0.0001	2.33(1.83, 2.85)	0.0001
Ext.(cm)	3.13(2.74, 3.53)	0.0001	2.6(2.2, 3.0)	0.0001
RLF (cm)	2.8(2.21, 3.39)	0.0001	2.8(2.21, 3.39)	0.0001
LLF (cm)	2.93(2.42, 3.45)	0.0001	2.87(2.35, 3.39)	0.0001
RR (cm)	3.0(2.44, 3.65)	0.0001	2.93(2.37, 3.49)	0.0001
LR (cm)	3.4(2.85, 3.96)	0.0001	3.6(3.05, 4.16)	0.0001
L. Chest (cm)	-1.0(-1.11, -0.89)	0.0001	-1.0(-1.11, -0.89)	0.0001
Up. Chest (cm)	-1.07(-1.25, -0.88)	0.0001	-1.07(-1.25, -0.88)	0.0001
M. Chest (cm)	-0.93(-1.11, -0.76)	0.0001	-0.93(-1.11, -0.76)	0.0001

VAS, Visual Analogue Scale; Flex, Flexion; Ext, Extension; RR, Right Rotation; LR, Left Rotation; RLF, Right Lateral Flexion; LLF, Left Lateral Flexion; L, lower; Up, upper; M, medium; MD, mean difference; CI, Confidence interval; p, probability value. * P-Value < 0.05 denotes statistical significance; data are mean± SD. * P-Value < 0.05 denotes statistical significance; data are mean± SD

with traditional stretching exercises, as investigated in this study, are less documented. While studies such as those by authors in [12] and [14] have noted improvements in cervical range of motion and muscle strength through various physical therapy techniques, the specific contribution of rib mobilization remains underexplored.

Our findings align with those of [10] and [13], which reported improvements in similar clinical outcomes following thoracic mobilization. However, the unique aspect of our study—the inclusion of rib mobilization—did not show additional benefits when compared to traditional stretching alone. This could suggest that the specific techniques of mobilization may not be as critical as previously thought, or that the duration of intervention in our study was too brief to detect any differential effects.

Further research is needed to explore these findings over longer intervention periods and with varied techniques to fully understand the potential differential impacts of thoracic versus rib mobilization in conjunction with traditional stretching exercises.

The findings of this study underscore the effectiveness of thoracic spine mobilization integrated within a passive stretching regimen, which improved resting pain intensity, active cervical range of motion, and chest expansion in patients with chronic mechanical nonspecific neck pain. These results align with previous research which suggests that therapeutic exercises combined with thoracic mobilization can treat symptoms of chronic mechanical nonspecific neck pain more effectively than exercises alone [15].

Thoracic mobilization specifically targets enhancements in chest expansion and respiratory function, both of which are often compromised in patients with chronic neck pain [11]. Our study supports existing literature by demonstrating that thoracic and rib mobilization not only improves thoracic kinematics and segmented thoracic mobility but also positively impacts cervical function, postural alignment, and overall respiratory function [9]. Furthermore, both thrust and nonthrust mobilizations of the thoracic spine have been documented to alleviate symptoms, decrease neck pain intensity, and enhance range of motion, ultimately reducing self-reported disability [10, 11].

Our findings suggest that the addition of rib mobilization could potentially open new therapeutic possibilities by further enhancing thoracic kinematics and cervical function. This approach appears promising in managing chronic mechanical nonspecific neck pain by improving the overall functional and postural alignment of the thoracic and cervical regions.

The utility of thoracic mobilization as a treatment for mechanical neck pain is well-documented, with systematic reviews generally affirming its positive impact [16, 17]. Despite this, there remains some discrepancy in the literature, as other reviews have noted mixed results regarding the effectiveness of thoracic spine treatments in managing neck pain [18]. This suggests that while thoracic mobilization is beneficial, factors such as treatment protocols, patient selection, and outcome measures might influence its efficacy.

Further emphasizing the potential of thoracic treatments, a study highlighted improvements in lower trapezius muscle strength following thoracic manipulation [8]. Similarly, conventional stretching exercises have been consistently beneficial, not only in reducing pain intensity but also in improving cervical range of motion and overall quality of life for patients with persistent, nonspecific mechanical neck pain [14, 18, 19]. These benefits align with findings from Jari Ylinen et al., who reported that manual therapy combined with stretching exercises effectively reduces short-term pain intensity in chronic mechanical neck pain sufferers [20].

Our findings contribute to this body of evidence by suggesting that integrating thoracic mobilization with conventional stretching might offer additional benefits. This underscores the potential of a multimodal approach in treating chronic mechanical neck pain, which could lead to more comprehensive management strategies. However, the relatively small sample size of our study limits the generalizability of these results. Future research with larger cohorts is essential to validate and expand upon our findings, potentially establishing more definitive evidence for the efficacy of combined treatment modalities.

Conclusions

This study demonstrates that thoracic mobilization combined with passive stretching exercises significantly reduces pain intensity, enhances active cervical range of motion, and improves chest expansion in individuals suffering from chronic mechanical nonspecific neck pain. These findings suggest that integrating thoracic mobilization into treatment regimens may offer considerable benefits for this patient population.

Conflict of interest

The authors declare no conflicts of interest related to this work.

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ORIGINAL ARTICLE

Linear and nonlinear programming: effects on the physical abilities of young basketball players

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Abstract

Background and Study Aim: Linear and nonlinear programming are methods used to control intensity and volume in sports training. Despite their widespread application, there is a lack of evidence-based studies that directly compare the effects of linear versus nonlinear programming. This study aims to assess the effect of linear and nonlinear programming on improving the power, agility, and endurance of young basketball players.

Material and Methods: This study employs a two-group pretest-posttest experimental design. It included 40 male basketball players aged 16-18, with weights ranging from 60 to 77 kg and heights from 167 to 180 cm. Participants were divided into two groups based on their ordinal pairings. The instruments used in this study were the jump DF, lane agility, and multistage fitness tests. Data were analyzed using descriptive statistics, Wilcoxon tests, and Mann-Whitney U tests, with the assistance of SPSS 23.

Results: The pretest-posttest findings for both the linear and nonlinear programming groups showed significant improvements in power, speed, and endurance, with Asymptotic Significance (Asymp. sig) 2-tailed values of less than 0.05. Comparative analysis of posttest results between linear and nonlinear programming indicated significant differences: power showed an Asymp.sig value of 0.009 with a difference of 3.1; agility showed an Asymp.sig value of 0.000 with a difference of 0.35; and endurance showed an Asymp.sig value of 0.002 with a difference of 2.08.

Conclusions: The study demonstrates significant differences in the impacts of linear and nonlinear programming on power, agility, and endurance among young basketball players. Both programming types significantly enhance these attributes, but nonlinear programming is more effective than linear programming in improving the physical abilities of young basketball players.

Keywords: linear, nonlinear, programming, physical abilities, young basketball players

Introduction

Physical ability is a crucial aspect of winning basketball matches. Optimal physical performance is achieved when the training program, prepared by the trainer, adheres to established training principles, dosage settings, and appropriate periodization. Periodization is a form of training management planned at a macro level and divided into smaller segments, allowing for focused stress management and programming [1]. It is classified into four types: traditional, undulating, inverted, and block periodization [2, 3, 4]. The core content of periodization involves programming that encompasses methodologies, models, and training dose settings [5]. In practice, programming often adopts linear and nonlinear models. Linear programming gradually increases intensity or volume, whereas nonlinear programming varies the intensity and volume in waves [6].

Numerous studies have explored different programming approaches in sports training. For instance, the impact of an 8-week linear periodization was assessed on young soccer players, revealing specific performance adaptations [7]. Similar studies have investigated reverse and traditional periodization in triathlon athletes over eight weeks [8], as well as both linear and nonlinear loading interventions aimed at enhancing leg muscle power in triathlon athletes and arm strength in javelin throwers [9, 10]. Additional research has examined various strength training methods, including adjustments of training intensity [11], and the effects of linear and nonlinear loading on muscle hypertrophy and strength [12]. The influence of periodic linear and nonlinear combinations has been studied in swimmers [13], while nonlinear periodization has been applied to general fitness [14] and specifically to improve the physique of soccer players [15]. The comparative effectiveness of linear versus nonlinear periodization during the maintenance phase for soccer players has also been scrutinized [16]. Furthermore, studies have

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assessed the application of circuit training with linear loading on basketball players [17], the impact of loading strategies on basketball players' muscle power [18], the enhancement of power in hockey players through nonlinear periodization [19], the evaluation of nonlinear periodization in basketball [20], and comparisons between linear and daily undulating periodization in basketball players [21].

The majority of studies reviewed focus on physical improvements through various periodization schemes including linear, nonlinear, and undulating programming, as well as comparing traditional and reverse periodization techniques. However, these studies predominantly involve sports like hockey, football, javelin throwing, and swimming. Notably, a targeted literature search using the keywords "linear," "nonlinear," and "basketball" revealed only three studies addressing linear and nonlinear programming's effects on basketball players' physical abilities. Additionally, the research highlights inconsistencies in the application of linear and nonlinear programming. These inconsistencies may arise from genetic differences between athletes, their physiological capacities for adaptation, and methodological limitations such as the absence of control groups in experimental setups [13]. Despite observing varying outcomes from linear and nonlinear programming, the differences in results were not significant enough to conclusively determine the superiority of one program over the other [22].

The authors critique the inconsistent usage of the terms "periodization" and "training load." They argue that periodization should be viewed as macro training planning that encompasses not only the scheduling over months, weeks, and days but also stress management and strategic programming [2]. Conversely, the term "load" typically refers to the resistance encountered during physical activities, quantifiable in newtons [23]. Therefore, the use of "scientific loading" in the context of sports and exercise science is deemed inappropriate as it misrepresents the nature of physiological loading [23]. Furthermore, exercise programming often employs the terms "linear" and "non-linear" to describe treatment protocols that are implemented over shorter periods [5]. It is emphasized that training programming should be meticulously structured to maximize athlete performance effectively [24].

Despite the widespread application and significant interest in periodization methods in sports training, there remains a notable scarcity of systematic studies comparing the effects of linear and nonlinear programming on the physical abilities of young basketball players. Most existing research does not fully explore how different periodization approaches impact key aspects of physical fitness such as power, agility, and endurance. This gap in the literature highlights the need for further research to compare these methodologies comprehensively to determine the most effective training strategies for young athletes.

The research aims to learn more about the effects of linear and nonlinear programming on young basketball players' physical abilities.

Materials and Methods

Participants

The study included 40 male basketball players aged 16 to 18 years, with weights ranging from 60 to 77 kg and heights between 167 and 180 cm. This research was conducted with the approval of the athletes' parents and the Ethics Committee of Semarang State University. All procedures adhered to the ethical standards laid out in the Declaration of Helsinki.

This experimental study employed a two-group pretest-posttest design to compare the effects of linear and nonlinear programming on physical abilities such as power, agility, and endurance. The sample comprised athletes who were 80% committed to attendance, had participated in at least one national championship, and had no history of injuries. Data collection methods included document analysis for problem rationalization, observations, and field testing with standardized instruments —multistage fitness test, vertical jump DF, and lane agility drill — ensuring high validity and reliability [25, 26, 27].

Participants were initially ranked based on pretest results and matched into pairs using an ordinal A-B-B-A subject matching pattern to ensure balanced distribution; 20 athletes were assigned to each programming group. The eight-week training program included six sessions per week, with intensity and volume adjustments specific to the type of programming. Each training session began with a coach-led warm-up consisting of five minutes of jogging to increase heart rate, followed by 20 minutes of combined static and dynamic stretching. This was followed by the main training component as outlined in Table 1.

Statistical Analysis

The data analysis technique employed included descriptive analysis, which provided the minimum, maximum, mean, and standard deviation values [28]. Normality tests were performed on the data, which were found to be not normally distributed. Consequently, nonparametric tests were utilized, specifically the Wilcoxon test, to compare the pretest and posttest results within the same groups. Additionally, the Mann-Whitney test was used to compare posttest results between different groups, with a significance level set at $p < 0.05$ [29]. Data analysis was facilitated using the Statistical Package for the Social Sciences (SPSS) version 23.

Table 1. Linear and nonlinear programming to increase power, agility, and endurance

Linear programming		
Material	**Exercise Dosage**	
Post 1: Power lay-up drill Post 2: Hurdle jump low Post 3: Defense shuffle Post 4: Lateral jump low (right) Post 5: Mirror drill Post 6: Lateral jump low (left)	Meeting: 1-6 Method: Circuit Intensity: 75% Pulse: 165/min Sets: 4-5-6-7 Recovery: 3 minutes	Meeting: 7-12 Method: circuit Intensity: 85% Pulse: 180/min Sets: 5-6-7-8 Recovery: 3 minutes
Post 1: Pro hop drill	Meeting: 13th-18th	Meeting: 19th-24th
Post 2: Hurdle jump high	Method: Circuit	Method: Circuit
Post 3: One-on-one drill	Intensity: 85%	Intensity: 85%-100%
Post 4: Lateral jump high (right)	Pulse: 180/min	Pulse: 180/min
Post 5: Box out drills	set: 10-11-12	sets: 12-13-14 sets
Post 6: Lateral jump high (left)	Recovery: 5 minutes	Recovery: 5 minutes
Nonlinear Programming		
Material	**Exercise Dosage**	
Post 1: Power lay-up drill	Meeting: 1-6	Meeting: 7-12
Post 2: Hurdle jump low	Method: circuit	Method: circuit
Post 3: Defense shuffle	Intensity: 75%	Intensity: 85%
Post 4:Lateral jump low (right)	Pulse: 165/min	Pulse: 180/min
Post 5: Mirror drill	Sets: 4-5-6-7	Sets: 7-8-9-10
Post 6: Lateral jump low (left)	Recovery: 3 minutes	Recovery: 3 minutes
Post 1: Pro hop drill	Meeting: 13-18	Meeting: 19-24
Post 2: Hurdle jump high	Method: Circuit	Method: Circuit
Post 3: one on one drill	Intensity: 100%	Intensity: 100%
Post 4:Lateral jump high (right)	Pulse: 180/minute and above	Pulse: 180/minute and above
Post 5: Box out drills	Sets: 4-5-6-7-8	Sets: 4-5-6
Post 6: Lateral jump high (left)	Recovery: 5 minutes	Recovery: 5 minutes

Results

Table 2 presents the results of the descriptive analysis, including pretest and posttest scores for both linear and nonlinear programming groups.

Table 2 illustrates that the mean posttest scores are higher than the mean pretest scores for both the linear and nonlinear programming groups, indicating improvements in all measured variables. Specifically, for the linear programming group, the mean posttest scores were 67.85 for power, 10.50 for agility, and 50.01 for endurance. In contrast, the nonlinear programming group showed even higher posttest scores with 70.95 for power, 11.77 for agility, and 52.09 for endurance.

Table 3 displays the results of the Wilcoxon test analysis, which compared pretest and posttest in similar groups.

The Wilcoxon test results presented in Table 3 demonstrate significant improvements in young basketball players' physical abilities following a linear programming intervention. Specifically, there was a noticeable increase in leg muscle power, with scores rising from a pretest mean of 65.95 to a posttest mean of 67.85, resulting in a statistically significant difference (Asymp.sig 2-tailed p = 0.000). Similarly, agility improved, evidenced by a reduction in scores from 11.65 to 10.50, also marked as significant (Asymp.sig 2-tailed p = 0.000). Lastly, endurance showed gains, increasing from a pretest score of 48.43 to a posttest score of 50.01, with the change denoting significant enhancement (Asymp. sig 2-tailed p = 0.000).

Overall, the linear programming intervention led to marked improvements in power, agility,

Table 2. Results of descriptive analysis of pretest and posttest scores

Linear Programming				
Variable	**Min**	**Max**	**Mean**	**Std.Deviation**
Pretest power	60	72	65.95	4.032
Posttest power	60	73	67.85	3.964
Agility pretest	11.31	12.26	11.6564	.28379
Agility posttest	10.09	11.41	10.5012	.41757
Endurance pretest	47.00	61.04	48.4335	3.66878
Endurance posttest	47.09	62.02	50.0140	3.75420
Pemrograman Nonlinear				
Variable	**Min**	**Max**	**Mean**	**Std.Deviation**
Pretest power	59	72	66.15	4.591
Posttest power	64	75	70.95	2.946
Agility pretest	11.31	12.58	11.7750	.39216
Agility posttest	9.34	11.01	10.1504	.32806
Endurance pretest	47.00	57.01	48.4280	3.10643
Endurance posttest	49.00	62.03	52.0945	3.79635

Table 3. Wilcoxon pretest and posttest results in each group

Group	**Variable**	**Mean**	**Selisih**	**Asymp.sig(2-tailed)**
Linear programming	Pretest power	65.95	1.9	0.000
	Posttest power	67.85		
	Agility pretest	11.65	1.15	0.000
	Agility posttest	10.50		
	Endurance pretest	48.43	1.58	0.000
	Endurance posttest	50.01		
Nonlinear programming	Pretest power	66.15	4.8	0.000
	Posttest power	70.95		
	Agility pretest	11.77	1.62	0.000
	Agility posttest	10.15		
	Endurance pretest	48.42	3.67	0.000
	Endurance posttest	52.09		

Table 4. Test results of the Mann-Whitney postest of linear and nonlinear programming groups

Group	**Variable**	**Mean**	**Difference**	**Asymp.sig(2-tailed)**
Linear programming	Power	67.85	3.1	0.009
Nonlinear programming		70.95		
Linear programming	Agility	10.50	0.35	0.000
Nonlinear programming		10.15		
Linear programming	Endurance	50.01	2.08	0.002
Nonlinear programming		52.09		

and endurance, with posttest results significantly surpassing pretest outcomes across all measured parameters.

The Wilcoxon test results presented in Table 3 indicate significant improvements for the nonlinear programming group across all tested variables. The power variable showed an increase in leg muscle power from a pretest score of 66.15 to a posttest score of 70.95, with a difference of 4.8, yielding a statistically significant Asymptotic Significance (Asymp.sig) 2-tailed value of less than 0.05 ($p = 0.000$). Agility improved as well, with scores decreasing from

a pretest of 11.77 to a posttest of 10.15, a difference of 1.62 that was also significant (Asymp.sig 2-tailed p = 0.000). Similarly, endurance scores increased from a pretest value of 48.42 to a posttest of 52.09, a difference of 3.67, with the change being statistically significant (Asymp.sig 2-tailed p = 0.000).

These results demonstrate that after undergoing nonlinear programming, participants showed substantial improvements in power, agility, and endurance, with posttest scores significantly exceeding pretest scores.

The results of the Mann-Whitney test, comparing the posttest scores of the linear and nonlinear programming groups, are detailed in Table 4. The analysis shows a significant difference in leg muscle power between the two groups; the linear programming group achieved a mean power value of 67.85, whereas the nonlinear programming group reached a higher mean of 70.95, with a notable difference of 3.1 and an Asymp.sig(2-tailed) value of 0.009, indicating significance ($p < 0.05$).

For agility, the linear programming group recorded a mean posttest score of 10.50, compared to 10.15 for the nonlinear group. This difference of 0.35 also demonstrated statistical significance with an Asymp.sig(2-tailed) value of less than 0.05 (p = 0.000), showing the nonlinear group's superior performance in terms of agility enhancement.

Similarly, in endurance, the nonlinear programming group outperformed with a mean score of 52.09 compared to 50.01 for the linear group, a difference of 2.08, also significant (Asymp. sig(2-tailed) p = 0.000), suggesting more effective endurance improvement in the nonlinear group.

Figure 1 graphically represents these comparisons, highlighting the differences in mean values between the groups.

Discussion

This study was designed to evaluate the effects of linear and nonlinear programming on enhancing endurance, power, and agility in young basketball players. The findings reveal that nonlinear programming significantly outperforms linear programming in improving these physical attributes. These results are consistent with another experimental study involving twenty-seven men who participated in resistance training for the upper extremities. This study divided participants into non-programmed, linearly programmed, and nonlinearly programmed groups, with findings indicating that nonlinear programming was superior in enhancing upper extremity strength over a 12-week training period [30].

Further supporting these findings, research on untrained elderly individuals demonstrated that 12 weeks of resistance training using nonlinear programming significantly enhanced their functional capacity [31]. Similarly, in young soccer players, resistance training employing nonlinear programming led to marked improvements in maximum strength, power, and agility [32].

Collectively, these results, corroborated by multiple studies, strongly suggest that nonlinear programming is more effective than linear programming in boosting power, agility, and endurance among young basketball players.

Furthermore, this study addresses a gap in existing literature, as no specific research has yet been found on the application of linear and nonlinear programming in youth basketball. This absence underscores the empirical novelty of our research. Prior studies have often conflated the definitions of training loading with programming approaches, where the application of linear and nonlinear programming was merely subjected to critical analysis without subsequent experimental investigation [33].

Our study, therefore, represents the first experimental research to distinctly define and apply linear and nonlinear programming within the context of basketball training. By doing so, it

Figure 1. Average posttest score (APS) for linear and nonlinear programming

not only clarifies these programming concepts but also directly tests their effectiveness, providing a pioneering contribution to sports science and training methodology.

Nonlinear programming in this study involves six components that integrate ballistic and agility exercises within a circuit training format, aimed at enhancing both anaerobic and aerobic endurance. Given the unique training adaptations of each athlete, nonlinear programming offers varied training dose settings. Ballistic exercises, commonly known as plyometrics, are crucial for improving physical fitness in team sports [34]. This type of training, when combined with strength exercises and sprinting 2-3 times weekly over 4 to 16 weeks, has been shown to enhance jumping performance, short-distance sprinting, and agility in both teenage and adult amateur athletes [35].

Moreover, incorporating both unilateral and bilateral plyometric exercises yields greater benefits than traditional or single-modality plyometrics [35]. Plyometrics involves a stretch-shortening cycle; muscles store energy during the eccentric phase and rapidly transition to the concentric phase during explosive movements like jumping and sprinting [36]. This process significantly boosts physical fitness attributes such as jumping, skipping, sprinting, and agility [37]. Additionally, the integration of ballistic training with circuit methods has been found to effectively improve endurance [38].

Circuit training, executed three times per week and comprising eight stations—including jump rope, commando dance, inverse sit-ups, squat jumps, jack-knife, push-ups, hurdle hops, and sit-ups—significantly enhances agility and endurance after ten weeks [39]. This form of training, characterized by relatively short intervals, is classified under high-intensity interval training (HIIT).

Additionally, a recent study on nonlinear programming, conducted three times a week for six weeks, utilized a regimen including medicine ball tosses, resistance band exercises, and both bilateral and unilateral plyometrics. This training markedly improved power, agility, and endurance [40].

Further supporting these findings, research indicates that physical training involving plyometrics, hurdle jumps, medicine ball exercises, and ballistic movements—conducted with high intensity and moderate to low volume three times a week for four weeks—substantially impacts both anaerobic and aerobic endurance [41].

Thus, a well-structured training program, especially in basketball, is crucial for enhancing physical performance and achieving optimal athletic outcomes.

The physical component of basketball is crucial and greatly influences a player's competitive capabilities. Every movement in the sport requires robust physical conditioning, which is enhanced through techniques such as drill methods and short intervals naturally incorporated into training sessions. Consequently, physical training is fundamentally essential in basketball, and effective programming principles are necessary to enhance physical fitness.

In this context, training programming can be likened to medical dosing: insufficient training intensity and volume will not yield significant improvements [42, 43]. Conversely, excessive training can lead to overtraining symptoms, just as an overdose of medication can be harmful. Thus, training intensity and volume must be meticulously calibrated, and aspects like nutrition and recovery must be prioritized to avoid detrimental effects on the athlete's body [42, 43].

Moreover, implementing effective physical programming requires adherence to fundamental training principles, including progressive overload, regularity, and individuality [43]. Additionally, basketball programming is intimately connected to pedagogy, which facilitates young players' self-exploration and talent development. This pedagogical aspect implies that athletes can integrate lessons learned in various settings, such as schools and clubs, enhancing both personal and social benefits [44].

Finally, a crucial aspect of programming is ensuring that the exercise regimen is successfully executed to maximize individual health and societal benefits [45].

In summary, this study underscores the critical importance of tailored programming in enhancing physical abilities such as power, agility, and endurance in young basketball players. While the advantages of nonlinear programming over linear programming have been demonstrated, there remains a broad spectrum of potential research that could further refine our understanding and application of these training methodologies. Future studies could explore the long-term effects of these programming strategies on athlete performance across different sports. Additionally, investigating the specific impacts on diverse age groups and skill levels within the basketball community could provide deeper insights into the scalability and adaptability of these training programs. Moreover, integrating technological advancements such as biometric monitoring could enhance the precision of training regimens and provide real-time feedback, thus optimizing training outcomes. Ultimately, expanding this research to incorporate a wider variety of physical, psychological, and environmental variables would offer a more comprehensive view of sports training's role in athlete development and performance.

Conclusions

This study reinforces the superiority of

nonlinear programming over linear programming in enhancing the physical capabilities of young basketball players, particularly in power, agility, and endurance. The findings advocate for the adoption of nonlinear programming approaches in sports training regimens. By doing so, trainers and coaches can more effectively tailor training programs to the specific needs of athletes, thereby optimizing their performance potential. As sports science continues to evolve, the principles of nonlinear programming offer a robust framework for developing athletic skills and should be considered a fundamental strategy in the preparation and conditioning of young athletes.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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ORIGINAL ARTICLE

Effect of lower extremity joint distraction exercises during warm-up on range of motion, flexibility, and jump performance in female volleyball players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim: Effective warm-up routines are critical for enhancing athletic performance and reducing injury risk. Joint distraction exercises are hypothesized to improve range of motion (ROM), flexibility, and jump performance, yet their effects are not well-documented in volleyball. This study aims to investigate the impact of joint distraction exercises applied to the lower extremities during warm-ups on ROM, flexibility, and jump performance in female volleyball players.

Material and Methods: Twenty-four female volleyball players voluntarily participated in this study. The standard protocol included routine warm-ups followed by pre-tests measuring flexibility, range of motion (ROM), vertical jump (VJ), and horizontal jump (HJ). After a 48-hour rest period to minimize fatigue effects, the athletes underwent joint distraction exercises using elastic bands targeted at the lower extremities. Post-tests were conducted after these specific warm-up exercises to assess any changes. Data analysis was performed using SPSS software.

Results: The study found no significant difference in hip flexion range of motion (ROM) scores following joint distraction exercises ($p > 0.05$). However, statistically significant improvements were observed in overall flexibility, ankle dorsiflexion ROM, and both vertical and horizontal jump performances ($p < 0.05$).

Conclusions: The study demonstrates that joint distraction exercises during warm-ups significantly enhance flexibility, range of motion (ROM), and jump performance in female volleyball players. Incorporating these exercises into routine warm-ups could be crucial for optimizing athletic performance and potentially reducing injury risks.

Keywords: warm-up, jumping, distraction, flexibility, range of motion

Introduction

In competitive sports such as volleyball, optimizing physical performance while minimizing injury risk is paramount. Despite the critical role of warm-ups in preparing athletes for peak performance, traditional routines often overlook targeted techniques that could enhance key attributes for volleyball players, such as flexibility, range of motion (ROM), and jump capabilities. Joint distraction exercises, particularly those applied to lower extremities using elastic bands, have emerged as a promising approach to enhance these physical qualities. Yet, the specific effects of these exercises during warm-ups have been underexplored, particularly in female volleyball players.

The importance of specialized warm-up techniques becomes even more evident considering the dynamic nature of volleyball, a sport characterized by open-skill movements performed at varying speeds [1]. These movements can lead to various injuries, including ankle and cruciate ligament injuries [2], which underscores the need for effective preventive strategies. Warm-up exercises play a crucial role in mitigating these injury risks and preparing athletes for the demands of the game. Various methods are employed in warm-ups to prevent sports injuries and increase flexibility [3]. Stretching exercises, which raise body temperature, prevent adhesions between soft tissues and bones, and enhance joint range of motion (ROM), are considered essential. Techniques such as static, ballistic, and dynamic stretching, along with proprioceptive neuromuscular facilitation (PNF), are commonly used during warm-ups to increase ROM [5, 6, 7, 8]. The exploration of joint distraction exercises fits into this context as a potentially valuable addition to the warm-up routines, promising enhanced flexibility and reduced injury risk without the downsides of traditional stretching

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methods.

Warm-up routines have been documented to improve various performance parameters such as strength, power, agility, sprint performance, vertical jump height, and electromyography activity during isometric muscle contractions [9]. Notably, compared to other stretching methods, dynamic stretching performed at various intensities is particularly effective at increasing body temperature, motor unit excitability, muscle activation time, kinaesthetic awareness, and range of motion (ROM) when used as part of a pre-exercise warm-up [10]. An alternative approach involves warm-up exercises with elastic bands, which can trigger post-activation potentiation (PAP) to enhance flexibility, ROM, sprint, agility, and jump performances [11, 12].

Building on these foundations, joint distraction exercises represent an innovative application of elastic bands in warm-up routines, specifically designed to boost athletic performance. These exercises have been shown to improve the maximum strength performance of lower extremity muscles and are aimed at enhancing ROM through increased synovial fluid production, which reduces friction between joint surfaces, facilitating smoother joint movements [12, 13, 14, 15]. Enhanced ROM is directly linked to improved sports performance, as it allows for greater muscular extension and retraction during athletic activities [16, 17].

Moreover, limited ROM, particularly in ankle dorsiflexion, has been identified as a significant risk factor for injuries in sports that involve intensive jumping, such as volleyball. Restrictions in ankle dorsiflexion can lead to a range of sports injuries, including cruciate ligament injuries, overuse disorders, patella injuries, Achilles tendinopathy, tibial shin splints, and anterior patella femoral pain syndrome [19, 20, 21]. Such limitations can alter knee valgus motion during jumping and squatting, disrupting the kinetic chain and potentially creating harmful force demands on the upper body [22]. Therefore, it is increasingly recognized that training through a full range of motion is essential to maximize the effectiveness of exercise routines and prevent injuries [23].

In summary, the existing body of research underscores the critical role of warm-ups in enhancing performance and preventing injuries among athletes, particularly in sports demanding high levels of physical exertion like volleyball. The documented benefits of advanced stretching methods, including dynamic and joint distraction exercises, have highlighted significant improvements in range of motion, flexibility, and sport-specific performance outcomes. However, despite these advances, the precise impact of joint distraction exercises during warm-ups has received limited attention, especially concerning their acute effects on volleyball players. This gap in the literature necessitates focused research to optimize warm-up protocols that could further benefit athletic performance and injury prevention.

In line with all this information, the main purpose of our study is to examine the acute effect of joint distraction exercises applied to the lower extremities during warm-up on range of motion and jumping performance in female volleyball players.

Materials and Methods

Participants

This study involved 24 female volleyball players from the Women's 2nd League of the Turkish Volleyball Federation in Istanbul. The participants had an average age of 17.71 ± 2.57 years, an average height of 174.87 ± 8.46 cm, and an average body weight of 66.79 ± 7.67 kg. All participants were actively competing, held a sports license, and had no knee injuries that could impede their range of motion, aligning with the study's inclusion criteria. Ethical approval was obtained from the Ethics Committee of Sakarya University of Applied Sciences (E-26428519-050.99-96228).

Research Design

The height (cm) and body weight (kg) of each participant were measured using a portable stadiometer and a TEM ECHO device, respectively, to ensure accuracy for subsequent jump tests analyzed via camera. Measurements were taken without shoes to ensure precision. The research protocol was adapted from the study by Çağlın et al. [14] and further details of the protocol are illustrated in Figure 1.

Initially, athletes underwent a 10-minute warm-up consisting of 5 minutes of walking followed by 5 minutes of running. Subsequently, vertical jump (VJ), horizontal jump (HJ), and flexibility-range of motion (ROM) tests were conducted at one-minute intervals. Two days later, the athletes performed lower extremity (hip-knee-ankle) joint distraction exercises consisting of 2 sets of 30 seconds with 15 seconds of rest between sets, following another 10-minute warm-up (Figure 2). Tests were replicated 5 minutes after completing the joint distraction exercises. All tests were administered in the same hall, at the same time of day, and with a two-day interval between sessions.

Testing Procedures

Vertical Jump (VJ): In the vertical jump test, athletes performed a squat on a non-slip flat surface, positioning their feet at a comfortable width. From the squat position, they were instructed to jump as high as possible using their full strength. No verbal encouragement or commands were given during the test to ensure consistency. The jumps were recorded using an iPhone 13 Pro equipped with a 60-fps video camera. The height of each jump was measured

Figure 1. Experimental procedure.

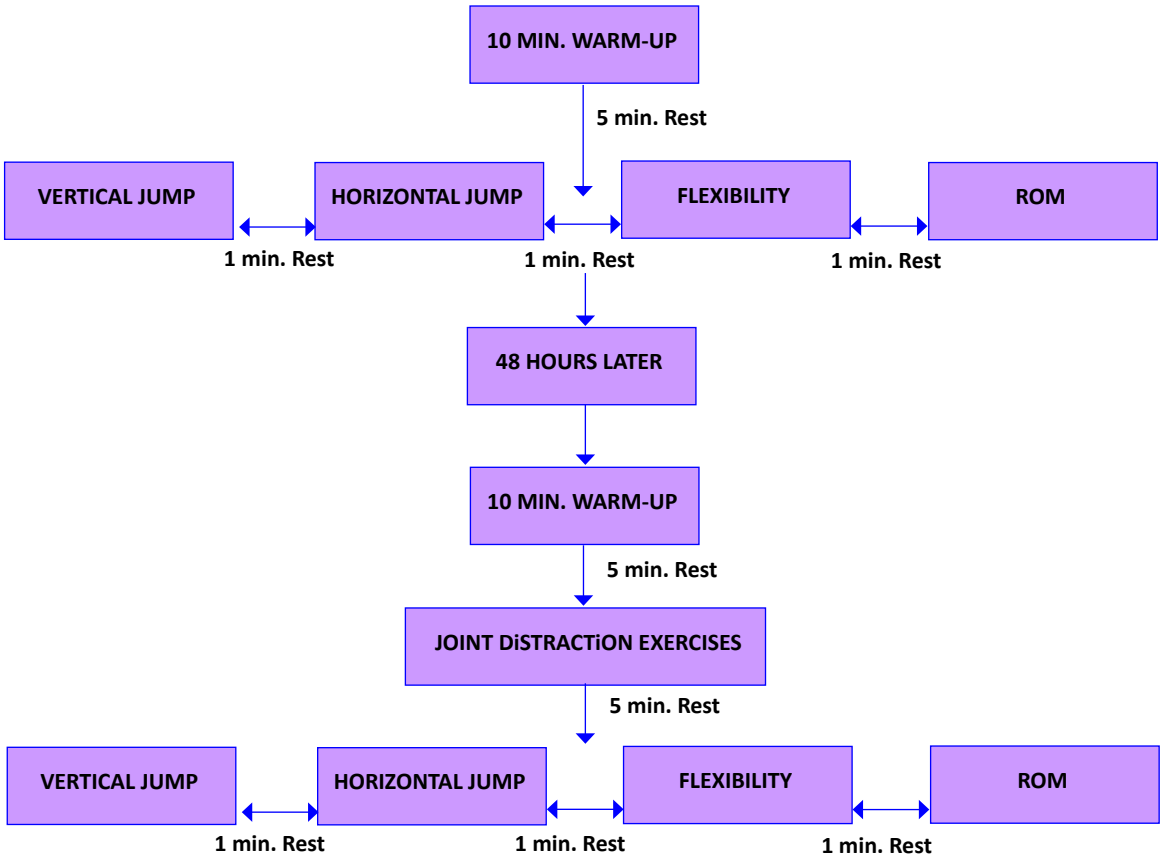

Figure 2. Joint distraction exercises

using the MyJump 2 mobile application [24].

Horizontal Jump (HJ): For the horizontal jump test, athletes were asked to jump horizontally from a marked line to the farthest point they could reach. The jumps were also recorded with an iPhone 13 Pro from both a height and a side angle to capture the entire jump trajectory. The distance of each jump was measured using the MyJump 2 smartphone application, with markings taken from the athletes' toes before the jump and heels after the jump [24].

Range of Motion (ROM): Athletes were asked to lie on their backs on a mat with both ankles and knees fully extended. Using the My Jump 2 app, which is validated for accuracy and reliability [24], an iPhone 13 Pro was positioned between the athlete's kneecap and the midpoint of the femur. Athletes were instructed to lift the straight leg as high as possible within 5 seconds.

Performed without shoes, athletes were asked to perform a lunge with one foot forward, touching the ground. The iPhone 13 Pro was placed in line with the midpoint of the tibia below the kneecap to measure dorsiflexion using the MyJump 2 app. Athletes were required to push their knee forward without lifting the heel for 5 seconds.

Flexibility Test (Sit and Reach): A sit-and-reach test was conducted using a specialized bench (Model 01285A, Lafayette, USA) with an 80 cm measurement length and 0.1 cm sensitivity. Athletes sat on the ground with legs extended straight, feet placed five centimeters apart with toes pointing upward and heels on the ground. Sitting at the starting line of the bench (marked at 23 cm), athletes reached forward along the measurement scale, pushing a movable bar as far as possible without bending their knees. The maximum reach was recorded after holding the position for two seconds. Each athlete performed the test twice, and the best score was used for statistical analysis.

Statistical Analysis

In this study, the SPSS (Statistical Package for the Social Sciences, Inc., Chicago, IL, USA) version 25 software was utilized for statistical analysis. Descriptive statistics of the athletes were conducted, and the Shapiro-Wilk test was employed to assess the normal distribution of the groups. A Dependent Sample T test was employed to compare the pre-test and post-test results of the athletes. The significance level was set at $p<0.05$.

Results

Table 1 presents a comprehensive comparison of the initial and final measurements for each assessed parameter, demonstrating the effects of the intervention on the athletic performance of the participants. According to the data, there was a statistically significant improvement in the flexibility, vertical jump (VJ), horizontal jump (HJ), and both left and right ankle dorsiflexion ROM measurements, with respective p-values of 0.026, 0.040, 0.040, 0.014, and 0.003. These results indicate notable enhancements in key athletic performance metrics following the intervention. Conversely, no significant differences were observed in the hip flexion ROM for both the left ($p = 0.772$) and right ($p = 0.758$) legs, suggesting that joint distraction exercises may not influence hip mobility within the parameters of this study.

Discussion

This study aimed to investigate the effects of joint distraction exercises on the lower extremities during warm-up, specifically assessing range of motion, flexibility, and jump performance in female volleyball players. The findings demonstrated statistically significant improvements in flexibility, vertical jump (VJ), horizontal jump (HJ), and ankle range of motion (ROM) for both the left and right ankles with p-values of 0.026, 0.040, 0.040, 0.014, and 0.003, respectively. While there were incremental increases observed in the left and right hip ROM (+0.49° and +0.95° respectively), these changes did not reach statistical significance ($p = 0.772$ for left hip and $p = 0.758$ for right hip).

Warming up is crucial for enhancing sports performance and reducing the risk of injuries. Various warm-up strategies, including those that involve joint distraction with elastic bands, are employed by athletes to achieve optimal performance levels and safeguard against injuries [25]. Joint distraction exercises involve applying a force that separates the joint surfaces, which can significantly improve joint mobility [26]. Although studies focusing on joint distraction with elastic bands during warm-ups are

Table 1. Comparison of Initial and Final Measurements of Athletes

Measurement	Initial Mean±SD	Final Mean±SD	p-value
Sit & Reach (cm)	30.33±8.48	32.0±7.85	0.003*
Left Leg Hip Flexion ROM (°)	76.59±5.20	77.35±5.86	0.439
Right Leg Hip Flexion ROM (°)	77.67±8.16	78.60±6.93	0.600
Left Ankle Dorsiflexion ROM (°)	47.31±7.41	49.83±8.09	0.010*
Right Ankle Dorsiflexion ROM (°)	46.77±9.39	50.10±8.84	0.000*
Vertical Jump (VJ) (cm)	30.83±5.16	32.18±4.44	0.001*
Horizontal Jump (HJ) (cm)	126.13±27.39	154.83±13.44	0.001*

limited, our findings are consistent with existing literature. We observed a significant improvement in flexibility scores from the sit-and-reach test after employing joint distraction exercises, a result that aligns with findings from other researchers who also reported significant enhancements in flexibility following similar interventions [13].

Improving the flexibility of athletes is widely acknowledged to positively impact their jump performance [27, 28]. Various studies support this relationship; for instance, researchers examining the physical performance of female athletes through traditional stretching and myofascial release found significant increases in both flexibility and jump performance [29]. Similarly, a study involving active university women reported enhancements in range of motion (ROM) and jump performance correlating with increased flexibility scores [30]. Further, dynamic stretching exercises were shown to positively affect ROM and vertical jump performances in young female artistic gymnasts [31], with another study highlighting that dynamic stretching led to improved jump performance in athletes [32].

Consistent with these findings, our study also demonstrated that joint distraction exercises significantly elevated both flexibility and jump scores among the athletes. This correlation reinforces the established notion that enhanced flexibility contributes to better jump performance, confirming the efficacy of joint distraction exercises in sports training protocols.

Limited ankle dorsiflexion range of motion (ROM) is a well-documented risk factor for injuries to the knee, ankle, shin, and hamstring in athletes [22, 33, 34]. This limitation also significantly impacts performance in sports like volleyball, where ankle joint ROM plays a crucial role [35]. Previous research has consistently shown that improvements in ROM can lead to enhanced jump performance. For instance, studies have demonstrated that athletes using elastic bands to increase their ROM scores see corresponding improvements in power performance [37, 38]. Driller and Overmayer [39] specifically noted that increases in ankle dorsiflexion angles were directly associated with higher vertical and long jump performances. Similarly, other studies have established a positive correlation between increased ankle mobility and enhanced vertical and horizontal jump capabilities [40, 41, 42]. Additionally, reduced vertical jump performance has been linked to low levels of ankle ROM [43].

The findings of our study corroborate these observations, reinforcing the critical role of enhanced ankle dorsiflexion ROM in improving jump performance and reducing injury risks among volleyball players. Our results confirm that joint distraction exercises effectively increase ROM and subsequently enhance athletic performance, aligning with the broader research landscape.

Elastic bands are increasingly favored in resistance training due to their provision of variable resistance loads, which can yield superior results in developing power, strength, and speed compared to traditional free weights [44]. Elastic band training has been utilized to increase muscle strength through enhanced range of motion (ROM) [45]. For instance, research involving 17 male bodybuilding athletes demonstrated that four joint distraction exercises using elastic bands during warm-ups significantly improved maximum repetition (1RM) squat performance [14]. Furthermore, studies suggest that exercises performed over a wider range of motion can offer greater benefits in terms of muscle strength and hypertrophy, linking increased ROM to muscle growth [46].

The application of proprioceptive neuromuscular facilitation (PNF) exercises with elastic bands has also shown significant health benefits. In patients with ankle instability, these exercises led to notable improvements in balance and muscle strength [47]. A 12-week intervention with elderly individuals using elastic bands resulted in enhanced joint ROM and muscle strength, suggesting that these exercises can effectively support aging populations [10]. Moreover, it has been reported that regular exercise with elastic bands can boost the quality of life in the elderly by positively impacting balance, endurance, and agility [48].

Notably, exercises using elastic bands have been found to improve jump performance more effectively than traditional training methods [49]. Additionally, a study using PNF exercises with elastic bands observed increases in strength and speed, further confirming the broad utility and efficacy of elastic bands in training [50].

These findings align well with the results of our study, which also observed improvements in flexibility, ROM, and jump performance through the use of joint distraction exercises with elastic bands in female volleyball players.

Athletes often employ various stretching methods prior to exercise, each of which must be carefully chosen based on timing and specific objectives [6]. Historically, research has demonstrated that static stretching performed before exercise might impair athletic performance, rather than enhance it [51, 52, 53, 54]. In contrast, dynamic stretching is generally recommended as it not only helps protect against sports injuries but also tends to improve overall sports performance. For example, a study involving artistic gymnastics athletes found that dynamic stretching notably increased both jump performance and ROM scores [31]. This supports the notion that dynamic stretching is particularly effective in enhancing ROM values among athletes [36].

Further, it has been observed that while static stretching does not lead to improvements in jump

performance, dynamic stretching has a positive impact [32]. Beyond static and dynamic stretching, self-myofascial release has also been shown to contribute to performance enhancements [13]. These findings suggest a complex relationship between the type of stretching used and the outcomes on athletic performance, emphasizing the need for carefully selected warm-up routines that include methods such as dynamic stretching or self-myofascial release to optimize performance effectively.

The review of literature indicates that diverse methods are employed during warm-ups to enhance performance and prevent injuries. The use of elastic bands is particularly prevalent across various sports disciplines. However, studies focusing specifically on joint distraction using elastic bands are relatively scarce [13, 14]. In our study, the application of joint distraction exercises with elastic bands led to significant improvements in sit-reach flexibility scores, ankle dorsiflexion ROM, as well as vertical and horizontal jump performances. It appears that the enhancements in jump performance can be attributed to the increased flexibility and ROM facilitated by these exercises. Given these results, incorporating joint distraction exercises with elastic bands into training routines and pre-competition warm-ups could be highly beneficial for athletes, potentially serving as a valuable tool for coaches aiming to optimize athletic performance.

The promising results of our study demonstrate the potential of joint distraction exercises with elastic bands in enhancing ROM, flexibility, and jump performance. Future studies should explore the long-term effects of these exercises on athletic performance and recovery, and how they compare with other flexibility and strength training modalities. Investigating the physiological mechanisms behind the improvements observed could lead to better tailored training protocols for various sports disciplines.

Conclusions

This study has established that joint distraction exercises with elastic bands significantly improve range of motion, flexibility, and jump performance in athletes. These findings highlight the exercises' potential benefits, particularly for athletes looking to enhance these specific performance areas. However, the study's limitations include its focus solely on female athletes and its examination of only the acute effects of the exercises. The impact on male athletes remains unexplored, and the differences between acute and chronic applications are yet to be understood. Expanding the demographic scope of future studies and exploring varied application durations could further validate and deepen the impact of joint distraction exercises.

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Conflict of Interest

The authors declare no conflicts of interest. The funders did not participate in the design of the study; nor in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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ORIGINAL ARTICLE

The effectiveness of cooperative learning strategy for mastery in enhancing the skill performance of some gymnastics floor movements

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim: In the rapidly evolving field of physical education, employing innovative teaching methods is crucial for enhancing student learning and skill acquisition. The aim of this study is to evaluate the effectiveness of a cooperative learning strategy specifically designed to enhance the mastery of gymnastics floor skills among physical education students.

Material and Methods: Thirty-six male students from Al al-Bayt University were divided into experimental and control groups using a quasi-experimental design. The control group received standard training, while the experimental group participated in a six-week, twelve-session educational program that employed a cooperative learning technique for skill mastery. The skills evaluated included Shoulder Stand, Front Handspring, Roundoff Back Handspring, and Front Balance.

Results: In every evaluated gymnastics floor movement, the experimental group demonstrated statistically significant improvements. Cooperative learning accounted for 51.8% of the variation in total skill competency, with substantial gains in individual skills: a 31.4% increase in front balance (mean score improved from 0.00 to 4.39), a 17% increase in shoulder stand (mean score improved from 0.06 to 4.67), a 25.2% increase in front handspring (mean score improved from 0.17 to 4.50), and a 41.1% increase in roundoff back handspring (mean score improved from 0.22 to 4.06). The experimental group's total gymnastics skill score was 17.61 (SD = 1.85), significantly higher than the control group's score of 13.50 (SD = 2.23). While the control group also showed improvements in gymnastics skills, the increases were less pronounced, with the roundoff back handspring mean score rising from 0.17 to 2.67 and the front handspring from 0.11 to 3.67.

Conclusions: The results of this study clearly demonstrate the benefits of using cooperative learning techniques in physical education, particularly in the context of teaching gymnastics floor routines. Besides significantly advancing skill mastery, this approach fostered a cooperative and supportive learning atmosphere. The effectiveness of the cooperative learning strategy in this context underscores its potential as an innovative teaching technique that can enhance student engagement, and promote a deeper understanding and retention of motor skills. Educators are encouraged to explore and adopt this strategy, extending its benefits to a wider variety of sports disciplines and educational settings, thereby enriching the pedagogical landscape of physical education.

Keywords: physical education, floor gymnastics skills, cooperative learning strategy, skill mastery, instructional techniques

Introduction

In the ever-evolving realm of physical education, the efficacy of instructional approaches directly impacts student involvement and academic achievements. Cooperative learning is particularly effective in skill-based disciplines like gymnastics. This pedagogical strategy, characterized by students engaging in collaborative work, improves both individual and group learning outcomes and meets the complex requirements of gymnastics, which demands mastery of individual skills as well as substantial teamwork and communication [1, 2]. Previous research has highlighted the advantages of cooperative learning in enhancing physical abilities and fostering a nurturing educational atmosphere [3, 4]. However, gaps still exist in understanding the full range of its effectiveness across various gymnastic movements.

Research indicates that choosing a teaching approach tailored to the needs of students significantly enhances their ability to grasp new material and achieve high competency levels in simpler skills before progressing to more challenging and complex ones. This strategy allows students with less formal education to benefit from increased repetition and focused attention, ultimately aiding the entire group in achieving high levels of

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competency [5]. Mastery learning is recognized as a crucial strategy in physical education programs, facilitating students' achievement of learning goals and offering a wealth of educational opportunities related to the skills they are acquiring. This approach is essential for balancing proficiency levels among students by providing each individual the time needed to master a skill at their own pace, without the pressure of a fixed schedule [6]. Previous studies have shown that implementing mastery learning in physical education significantly improves student performance on skills, fosters positive attitudes, and motivates students to achieve their goals [7].

A large corpus of research has explicitly examined how cooperative learning affects gymnasts' ability to develop new skills. It was emphasized that cooperative learning environments, where students gain knowledge through peer modeling and feedback, result in enhanced performance and skill acquisition [8]. It is clear from navigating the domains of physical education and gymnastics that incorporating cutting-edge teaching approaches, such as cooperative learning strategies, not only meets the needs of the modern knowledge economy but also addresses the complex challenges posed by gymnastics research. Investigations into current issues in gymnastics, such as biomechanics, motor control, and coaching practices, underscore the urgent need for flexible, student-centered pedagogical approaches that can foster a deep understanding and mastery of complex skills. As evidenced by the ground-breaking works [9, 10], this endeavor aligns with the pursuit of more integrated teaching methodologies that cater to the diversity of learners' needs while striving for excellence in skill acquisition.

A previously conducted study investigated the effect of a training program using the mastery learning method on the skill of vaulting in gymnastics among a sample of 25 students, who were randomly divided into an experimental and a control group. The program lasted four weeks, with sessions held three times per week, utilizing a quasi-experimental design. The results highlighted the effectiveness of the educational program, leading the researcher to recommend its adoption for teaching similar skills [11].

Another study examined the effectiveness of cooperative and collaborative learning strategies on the acquisition of table tennis skills among primary-stage students. Employing a quasi-experimental method, this study involved a sample of 50 students divided into three groups: one control group and two experimental groups. The findings demonstrated that cooperative and collaborative teaching methods significantly enhanced the acquisition of specific table tennis skills [12].

It was discovered that integrated mastery teaching methods surpassed traditional methods in teaching basketball skills, according to a study investigating the effects of sequential mastery and exercise scheduling on basketball skill development. The study also examined differences between two groups in pre- and post-tests. Employing a quasi-experimental design, the researchers worked with a sample of 60 students, concluding that scheduled exercises are crucial when teaching beginners [13].

Furthermore, previous research has highlighted the value of cooperative learning techniques in improving gymnastics skill mastery, noting significant gains in student motivation and performance [14, 15]. Additionally, there is a crucial need for diversity and interaction in teaching methods and the adoption of modern approaches [16].

Nevertheless, despite the apparent advantages of this approach, there is still a lack of research on the systematic implementation and assessment of cooperative learning in physical education, particularly within the context of gymnastics education. There is a pressing need for research on innovative teaching techniques, especially those that incorporate cooperative learning processes to aid gymnasts in mastering new skills.

The investigation of cooperative learning tactics in physical education has received considerable focus in recent years, marking a crucial transition from conventional teaching methods to more collaborative and student-focused approaches. The importance of social interaction in educational settings is particularly emphasized. Research has suggested that cooperative learning not only facilitates the development of physical abilities but also cultivates social skills and team cohesion among students [17]. Moreover, studies have revealed psychological advantages associated with these tactics, such as heightened motivation and self-esteem, thereby demonstrating the comprehensive influence of cooperative learning on student development [18]. The incorporation of mastery learning in cooperative environments presents a thought-provoking viewpoint on personalized learning trajectories within group settings, ensuring that every learner achieves proficiency at their own pace [19]. The intricate interplay between collaborative learning and the acquisition of motor skills is especially notable within the realm of gymnastics, where studies have shown that students engaged in cooperative learning environments experience significant enhancements in their performance. This underscores the efficacy of these tactics in fostering the development of complex skills [20].

Ultimately, the growing body of research on cooperative learning in physical education provides a compelling argument for its adoption as a fundamental teaching strategy. The aim of this study is to evaluate the effectiveness of a

cooperative learning strategy specifically designed to enhance the mastery of gymnastics floor skills among physical education students.

Materials and Methods

Participants

Thirty-six male undergraduate students, ages 19 to 23, from Al al-Bayt University's Department of Physical Education participated in the study. Enrollment in the gymnastics course and lack of prior experience with cooperative learning practices in gymnastics were prerequisites for selection. Random assignments were made to place participants in the experimental group (18 total) or the control group (18 total).

Ethical Approval Statement

This study followed ethical guidelines. All participants were informed about the study procedures, and informed consent was obtained from each participant.

Research Design

Pre- and post-tests were utilised in a quasi-experimental manner to evaluate gymnastics skills. The control group received standard gymnastics instruction, while the experimental group participated in a 6-week programme that included cooperative learning techniques for gymnastics expertise. The same pre- and post-intervention skill tests were given to both groups.

Research Design: Experimental Group

1. *Cooperative Learning Framework:* We adopted a structured cooperative learning framework where students actively engaged in various gymnastics tasks. These tasks included skill rehearsal exercises, collective sequences, and cognitive challenges related to gymnastics maneuvers, all designed to require collaborative effort for successful completion.
2. *Task Structure:* Each task was crafted to necessitate active involvement from all group members, fostering a sense of shared responsibility and mutual support. Tasks were varied to cover different aspects of gymnastics, ensuring comprehensive skill development.
3. *Motivation and Rewards:* Students were encouraged to collaborate to achieve shared objectives. Positive interdependence was promoted through shared rewards or recognition for group accomplishments, reinforcing the value of teamwork.
4. *Accountability:* Each student was accountable for their individual contributions to the group's success. This accountability was monitored through regular peer assessments and reviews of individual performances, ensuring fair and active participation.
5. *Development of Interpersonal Skills:* The cooperative tasks were also designed to help students develop crucial interpersonal skills such as communication, leadership, and conflict resolution. Techniques such as group discussions, role-playing, and peer feedback sessions were employed to enhance these skills.
6. *Role of the Teacher:* Teachers in the experimental group served as facilitators rather than traditional instructors. They provided necessary guidance, feedback, and support, utilizing cooperative learning strategies such as Jigsaw, Think-Pair-Share, and other group-based activities to enhance student engagement.
7. *Reflective Practices***:** Reflection and critique were integral parts of the learning process, aimed at enhancing metacognitive awareness and promoting continuous improvement. Students engaged in self-assessment and peer review sessions to evaluate their progress and identify areas for improvement.

Expected Outcomes: The implementation of this cooperative learning methodology was expected to lead to enhanced gymnastics skills, improved teamwork and communication abilities, and increased self-efficacy among students. The educational environment thus cultivated allowed students to assume responsibility for their own learning and to support each other in achieving their educational goals.

Evaluation: The effectiveness of the cooperative learning approach would be evaluated based on the progress in gymnastics skills, the development of teamwork and interpersonal skills, and the overall satisfaction of the students with the learning process. Standardized assessments, as well as feedback from students and teachers, would be utilized to measure these outcomes.

Research Design: Control Group

1. *Traditional Training Framework:* The control group underwent a conventional training regimen that included general physical fitness activities and sport-specific drills that are commonly integrated into physical education programs.
2. *Session Structure:* The frequency and duration of the sessions were identical to those of the experimental group to maintain comparability. Sessions were conducted for a set number of minutes or hours per week, typically three times per week.
3. *Educational Materials:* The training utilized traditional physical education resources such as textbooks, instructional videos, and written guidelines detailing the exercises and activities to be performed.
4. *Instructional Approach:* The teaching method was predominantly teacher-centered, with instructors leading the sessions and directly

guiding students through the exercises and tasks. This approach focused on direct instruction and individual performance rather than group interaction.

5. *Curriculum Focus*: The curriculum emphasized skill acquisition, physical fitness enhancement, and sportsmanship. The activities were designed to improve general physical capabilities and sport-related skills, aligning with typical educational goals in physical education.
6. *Evaluation and Monitoring:* The performance and progress of the control group were assessed using standardized measurements and teacher observations to ensure adherence to the training program. Periodic evaluations were conducted to monitor improvements in physical fitness, skill mastery, and other relevant outcomes.

Expected Outcomes: The traditional training approach was expected to result in improvements in individual gymnastics skills and physical fitness, providing a standard against which the cooperative learning approach of the experimental group could be measured.

Evaluation: Effectiveness of the traditional training method was evaluated by comparing the baseline physical skills and fitness levels with those achieved post-intervention. This comparison helped to isolate the effects of the cooperative learning strategy and assess its efficacy relative to conventional teaching methods.

Evaluation of Gymnastic Skills: Procedures and Tests

Gymnastic Skills Assessed:

1. *Floor Exercises:* The assessment covered fundamental tumbling moves such as front handsprings, back handsprings, cartwheels, and round-offs. These skills were evaluated for their technical execution and alignment with gymnastic standards.
2. *Apparatus Skills:* Depending on the study's design, participants were tested on various gymnastics apparatuses including the balance beam, uneven bars, vault, and parallel bars. Routine elements like hops, leaps, spins, and balances, which are integral to gymnastics routines, were also assessed.

Assessment Standards:

- *Methodology:* Evaluations focused on the execution of each skill, emphasizing correct body placement, technique, and alignment.
- *Difficulty:* Skills were assessed based on their complexity and adherence to established gymnastics progression criteria.
- *Artistry:* Artistic skills, including dance moves and choreography, were evaluated for gracefulness, fluidity, and expression.
- *Safety:* Safety standards were crucial, with assessments ensuring controlled landings and the use of proper spotting techniques to prevent injuries.

Test Administration:

- *Environment:* Assessments were conducted in a controlled environment, such as a dedicated gymnastics facility or an indoor gymnasium, to ensure consistency and safety.
- *Evaluators:* Trained professionals, such as gymnastics coaches or judges, administered the tests using standardized procedures to ensure reliability and fairness.
- *Procedure:* Participants performed each skill or routine element individually. Evaluators provided immediate feedback and scored each performance based on the predefined criteria.
- *Documentation:* Performances were either video recorded or observed live for detailed analysis and scoring. Results were systematically recorded for each participant, providing scores for individual skills and overall performance metrics.
- *Recording Tools:* Assessment scores were documented using standardized evaluation forms or digital platforms designed specifically for gymnastics evaluations.

Outcome Measurement: The success of the cooperative learning intervention was assessed by compiling and analyzing the performance data, which included individual skill scores and overall performance measures. This comprehensive evaluation allowed for a precise interpretation of the intervention's effectiveness in enhancing gymnastic skills through cooperative learning methodologies.

Statistical Analysis

Data were analyzed using SPSS version 25. Descriptive statistics (mean, standard deviation) were calculated for all variables. A paired sample t-test was used to compare pre- and post-test scores within groups, while an independent samples t-test was used to compare the changes between groups. The level of significance was set at $p<0.05$.

Results

To compare the pre- and post-test performance of the experimental and control groups, an independent samples T-test was used (Table 1). The findings indicate:

- The pre-test results for the two groups did not differ significantly, which allows for an accurate assessment of the intervention's impact.
- The experimental group demonstrated a significant advantage in post-test scores, with higher mean scores achieved for all skills examined. Specifically, the experimental group's total gymnastics skill score was 17.61 with a standard deviation of 1.85, compared to the control group's score of 13.50 with a standard

deviation of 2.23."

Compared to the control group, our analysis revealed significant improvements in the gymnastics skills performance of the experimental group. This group participated in cooperative learning-based training, demonstrating significant gains from the pre-test to the post-test in all assessed skills (Table 2). The experimental group demonstrated remarkable improvements in specific areas:

- The mean score for the Roundoff Back Handspring Skill increased from 0.22 to 4.06, whereas in the control group, it increased from 0.17 to 2.67.
- The experimental group's mean score for the Front Handspring Skill rose from 0.17 to 4.50, compared to the control group's increase from 0.11 to 3.67.
- The experimental group also showed higher improvements in the Front Balance Skill and Shoulder Stand Skill, with mean increases from 0.00 to 4.39 and from 0.06 to 4.67, respectively."

These findings suggest that the cooperative learning approach significantly enhanced the participants' ability to perform complex gymnastics maneuvers. Table 3 presents the arithmetic means and standard deviations for the entire skills test

Table 1. Independent samples t-test results for gymnastics skills tests between experimental and control groups

Variable	Group	Number	Mean	SD	T	DF	P-Value
Roundoff Back Handspring Skill	Experimental	18	0.17	0.51	0.410	34	0.684
	Control	18	0.11	0.32			
Front Handspring Skill	Experimental	18	0.22	0.43	3.88	34	0.701
	Control	18	0.17	0.38			
Front Balance Skill	Experimental	18	0.06	0.24	1.00	34	0.324
	Control	18	0.06	0.24			
Shoulder Stand Skill	Experimental	18	0.00	0.00	0.000	34	1.00
	Control	18	0.06	0.24			
Total score for gymnastics test	Experimental	18	0.44	0.62	0.297	34	0.768
	Control	18	0.39	0.50			

Table 2. Mean and standard deviations for the scores of the experimental and control groups on the gymnastics skills test in the pre-test and post-test

Variable	Group	Number	Pre-Test		Post-Test	
			Mean	SD	Mean	SD
Roundoff Back Handspring Skill	Experimental	18	0.22	0.43	4.06	1.00
	Control	18	0.17	0.38	2.67	0.91
Front Handspring Skill	Experimental	18	0.17	0.51	4.50	0.62
	Control	18	0.11	0.32	3.67	1.03
Front Balance Skill	Experimental	18	0.00	0.00	4.39	0.70
	Control	18	0.06	0.24	3.28	1.23
Shoulder Stand Skill	Experimental	18	0.06	0.24	4.67	0.59
	Control	18	0.06	0.24	3.89	1.02

Table 3. Arithmetic means and standard deviations of the experimental and control groups on the total gymnastics skills test before and after the intervention

Group	Number	Pre-Application		Post-Application	
		Mean	SD	Mean	SD
Experimental Group	18	0.44	0.62	17.61	1.85
Control Group	18	0.39	0.50	13.50	2.23
Total	36	0.42	0.55	15.56	2.90

before and after the intervention. The observed variations in averages between the two phases (pre- and post-application) confirm the positive effects of the cooperative learning technique on student outcomes in physical education settings.

Discussion

The objective of this study was to assess the effectiveness of a 6-week cooperative learning program aimed at improving gymnastic skills among students during physical education classes. Our findings corroborate previous research that highlights the benefits of collaborative learning for skill enhancement and fostering positive social relationships among students [12, 13, 14]. Additionally, prior studies have demonstrated that cooperative learning environments are effective in enhancing both skill development and social competencies in educational settings [12, 15].

Our findings further support and expand upon previous research, demonstrating statistically significant enhancements in all assessed gymnastic floor motions for individuals in the experimental group. This observation aligns with prior studies, which have shown that cooperative learning can significantly improve physical education outcomes [14, 15, 16]. We observed notable improvements in specific skills: a 31.4% increase in front balance, a 17% increase in shoulder stand, a 25.2% increase in front handspring, and a 41.1% increase in roundoff back handspring. These findings are consistent with studies conducted by Mitchell et al. [12] and Rocamora et al. [20], which also reported improvements in physical abilities through cooperative learning methods.

However, our study diverges from the research by Fernández-Espínola et al. [18] and Bores-García et al. [17] by specifically focusing on the impact of collaborative learning on precise gymnastic skills rather than on general physical fitness or motor skills. We provide a detailed analysis demonstrating that certain skills, particularly those requiring advanced coordination such as the roundoff back handspring, are more effectively improved through cooperative learning. This detailed examination offers fresh perspectives on the efficacy of cooperative learning in teaching, highlighting its unique benefits for complex movements that require a high level of precision and synchronization.

Moreover, when comparing our findings with previous research, we note a significant disparity in the level of advancement in specific abilities. For instance, the progress in the shoulder stand ability showed only a minor increase compared to the significant advancements recorded by Abdel-Aziz Issa [9] and Farana et al. [10] in their studies using similar cooperative learning methods. This variation in results can be attributed to the focused and rigorous implementation of the cooperative learning approach in our research, which emphasized ongoing peer feedback and collaborative practice sessions.

Results obtained from comparable research conducted in the domain of physical education and collaborative learning [12] discovered that incorporating cooperative learning strategies into the instruction of sport concepts and skills resulted in a notable increase in student engagement and skill acquisition. This suggests that students not only enhanced their sport-specific abilities but also developed improved social interactions and teamwork capabilities. In the same vein, studies have underscored the favorable impact of cooperative learning interventions on students' inherent motivation in physical education environments [18]. These studies emphasized that these pedagogical methods substantially enhance students' motivation levels, which are crucial for maintaining long-term involvement. Moreover, it was determined that cooperative learning not only improves outcomes in physical education but also cultivates an inclusive and supportive educational atmosphere [17]. Another study evaluated the effectiveness of the flipped classroom and cooperative learning approaches [19]. The results indicated that cooperative learning environments led to notable enhancements in acquiring gymnastic abilities, surpassing the outcomes observed in traditional settings. Furthermore, evidence was provided in support of the idea that incorporating cooperative learning might enhance performance in intricate physical abilities [20]. This finding suggests a consistent pattern across various instructional approaches and educational settings. These examples serve as a foundation for examining the alignment or divergence of your findings with previous research, thus enhancing the comparative analysis in the discussion portion of your publication.

A study conducted by Mitchell et al. [12] examines the utilization of cooperative learning methodologies in teaching sport concepts and skills. This study determined that using such tactics had a significant impact on increasing student involvement and improving their skill acquisition, both of which are crucial for achieving effective learning outcomes in physical education. Prior research has documented the advantages of cooperative learning in enhancing physical abilities and fostering a nurturing educational atmosphere [3, 4]. These studies establish a foundational understanding of the benefits of cooperative learning, particularly in skill-based disciplines such as gymnastics, which require both individual mastery and significant teamwork and communication. This body of knowledge is further enriched by studies specifically examining the application of cooperative learning to tactical games approaches in sports education.

While this approach is validated by earlier findings [12, 15], a critical view might suggest that the reliance on tactical games limits its broader application to other aspects of physical education that involve less structured or more individualized sports disciplines. Studies highlighted in the introduction cover a wider range of physical education activities, suggesting that the benefits of cooperative learning might be more universally applicable [3, 4]

Moreover, previous studies, such as those by [18, 19], have pointed out that cooperative learning not only improves physical skills but also psychological aspects like intrinsic motivation and self-esteem. This suggests a potentially significant impact of cooperative learning that extends beyond physical skill enhancement to include emotional and social development. Incorporating these broader results allows us to propose that further research should explore how cooperative learning strategies can be adapted or modified to benefit a wider array of physical education settings, ensuring that all aspects of student development are supported. This nuanced approach to the discussion helps contextualize our study within the larger framework of existing research [3, 4, 12, 18, 19], offering a more comprehensive analysis and demonstrating the multifaceted benefits of cooperative learning in physical education.

This comprehensive analysis illustrates both the promise and the limitations of cooperative learning in physical education. While our findings underscore the effectiveness of this approach in enhancing physical skills and social dynamics within the learning environment, they also reveal areas that require further exploration to generalize the results. One critical limitation noted is the study's reliance on a tactical gaming approach and a relatively small sample group, which may not fully represent the broader population or the diverse contexts of physical education. Furthermore, the study's emphasis on qualitative assessments raises questions about the measurement's objectivity and preciseness.

To address these gaps, future research should consider expanding the participant base to include a wider demographic and explore the implementation of cooperative learning across various sports and educational settings. Additionally, incorporating a mixed-methods approach that combines qualitative insights with quantitative data can provide a more robust evaluation of the impacts of cooperative learning strategies. Such an approach would not only validate the findings but also enhance the adaptability of teaching practices, tailored to meet individual student needs more effectively. This could ultimately lead to a more nuanced understanding of cooperative learning's role in physical education, ensuring it supports comprehensive student development—physically, socially, and emotionally.

Our work adds essential new insights to the current literature on cooperative learning in physical education, specifically in the context of gymnastics, by using comparative analyses and exploring these subtle differences. However, further research is needed to examine the long-lasting impacts of cooperative learning on the retention and practical use of skills, as well as its effectiveness across different sports disciplines. Moreover, it is necessary to further investigate the role of instructor facilitation in maximizing the advantages of cooperative learning activities.

Conclusions

The results demonstrate that the use of cooperative and mastery learning strategies significantly enhances students' skills in floor gymnastics exercises, outperforming more conventional teaching strategies. To enhance the training of gymnastics floor skills, it is crucial to strategically integrate multiple instructional modalities.

To effectively address the diverse requirements of students and promote optimal skill development in gymnastics floor routines, a range of teaching methodologies should be utilized. It is particularly recommended to employ the cooperative learning approach for mastery while improving performance in gymnastics floor skills. This indicates that broader application of this strategy in other study populations and sports training programs may yield positive effects. Additionally, teachers should be made aware of the benefits of incorporating various teaching pedagogies into the design of customized training curricula, thereby creating a comprehensive and productive learning environment that meets the diverse interests and skill levels of students.

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ORIGINAL ARTICLE

Age-stratified EUROFIT scores and differences of rural and urban male children in Kosovo

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Abstract

Background and Study Aim: Since its inception in 1988, the EUROFIT database network has expanded significantly. This expansion has facilitated the use of standardized test batteries to evaluate physical fitness across diverse groups. This study therefore aimed to determine possible differences in EUROFIT scores between rural and urban male children in Kosovo aged 7 to 11 years and to suggest the underlying factors besides the differences.

Material and Methods: The study involved 500 schoolchildren from Kosovo, both rural and urban, aged between 7 and 11 years. They were equally distributed within the total sample. Measurements were conducted using EUROFIT and anthropometric tests. The results were subsequently analyzed and compared using a Student's t-test.

Results: The data revealed that urban children have a better starting point, benefiting from greater access to organized physical activities. Their diets, while less healthy, may enhance physical power. The rural environment fosters healthier growth and skill development in boys, particularly before and during the onset of puberty.

Conclusions: Urban children should maintain their regular organized physical activities throughout the school period. This will help them match their rural peers in terms of motor and functional abilities. However, morphological traits are becoming more similar between these groups as they enter the prepubertal stage. Future studies should investigate potential differences in female samples. They should also extend to other countries and regions to provide a broader perspective.

Keywords: EUROFIT, boys, reference values, kids, physical fitness

Introduction

The persistent challenge in assessing physical fitness results among children necessitates a standardized reference system for accurate evaluations. As societies evolve, discrepancies in physical activity levels and access among urban and rural children have become more pronounced, raising questions about the adequacy of current fitness benchmarks. To correctly evaluate or compare a certain physical fitness result, a reference system is essential. Reference values databases are crucial, serving professionals to evaluate and track progress in children and practitioners more precisely. Profiling is a method for standardization of motor ability (reference) values, and such values are valuable data for further evaluations and comparisons of the next generations [1]. The usefulness of these databases depends on the sample, which should possess characteristics similar to the comparing group.

Stratification of samples can be achieved based on characteristics such as sex, age, environment, activity level, sport, sports group, and workplace. However, there is no ideal 'twin' group or database for any group, as each cohort exhibits unique variability. The EUROFIT test battery is considered the best solution for the standardized network of databases due to its cost-effectiveness and broad applicability. Its use across various age groups aids in assessing general health, evaluating and fostering regular exercise habits and sports participation, providing physical education teachers and coaches with insights into the structural and functional characteristics of children, developing national norms, and shaping national policies concerning children [2, 3, 4, 5].

Regarding EUROFIT, the most extensive study to date that involved EUROFIT testing in children was a systematic review conducted by Tomkinson et al. [6]. This study compiled results from EUROFIT analyses

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on children across 30 European countries, excluding Kosovo. The analysis revealed that boys consistently outperformed girls in tests of muscular strength, power, endurance, speed-agility, and cardio-metabolic fitness, but lagged behind in flexibility. Additionally, physical fitness improvements were more rapid in boys than in girls, particularly during their teenage years. While there exists a study on youth performance with EUROFIT in Kosovo focusing on the pubertal age group (11-17) [7], it indicated not only the expected sex differences and age-growth correlations but also highlighted that Kosovar students outperformed their peers in other countries in terms of anthropometric characteristics and speed/agility of limbs. However, they fell short in flexibility and endurance compared to peers from other countries. No studies have yet explored the potential differences in EUROFIT scores between rural and urban children in Kosovo across generations, especially among males and younger age groups.

This study aims to determine possible differences in EUROFIT scores between rural and urban male children in Kosovo, separately by age (7-11), and to suggest the underlying factors besides the differences.

Material and Methods

Participants

This study was conducted with a sample of 500 male schoolchildren from both rural and urban areas. The participants were divided by age into ten groups: 7, 8, 9, 10, and 11 years old. The sample comprised students from various primary schools, and the selection was based on a simple random sampling method. Participants were initially invited to join the study via the institution's communication channels, and parental written consent was obtained. Ethical approval was secured from the Governing Council of the University of Prishtina 'Hasan Prishtina' in Prishtina (Kosovo), under protocol number 677 dated 24.03.2023, as approved by the University's Ethics Committee. The research adhered to the principles of the Declaration of Helsinki.

Study Design

The project was conducted from April 2023 to June 2023 within the standard school environment, specifically during regular physical education and health classes. Measurements were performed by professionals in the fields of kinesiology and medicine, who had undergone prior training in anthropometric and motor measurements. Motor skills were assessed using the EUROFIT battery tests, a standardized test suite developed by the Council of Europe for primary school children [8]. Measuring instruments were selected to align with these tests.

The test battery consisted of the following assessments: Flamingo balance test (static body balance), Plate tapping (movement frequency), Sit-and-reach, Standing broad jump (explosive strength), Sit-ups in 30 seconds (repetitive abdominal strength), Bent arm hang (isometric static strength of upper body), 10x5 Shuttle run (running velocity), and 20m Beep test (cardio-respiratory fitness). Anthropometric measurements followed the protocols of the International Biological Program (IBP). According to this program, although there are 39 linear measures, only seven were used in this research: body height, length of the sitting trunk, arms length open, triceps skinfold, abdominal skinfold, subscapular skinfold, and body weight. Body height, length of the sitting trunk, and arms length open were measured using the *Martin Anthropometer* with a precision of ± 0.01 kg scale. Skinfolds were measured using an *Accu-Measure Body Fat Caliper*, and body weight was assessed using a *TANITA diagnostic scale (BC 418)*.

Statistical Analysis

Statistical analysis was conducted using two PC programs: Statistica 14 by TIBCO Software Inc., and Microsoft Excel for Mac OS Version 16.43. Descriptive statistics were calculated for all subgroups, and T-tests were performed to determine differences between groups. The significance level for this study was set at 0.05.

Results

The authors investigated potential differences in EUROFIT test results between urban and rural male children according to their age through T-test analysis. The data are presented below (Tables 1-5).

Examining the results of seven-year-old boys (Table 1), significant differences were observed in only two EUROFIT variables: the Standing broad jump, where urban boys outperformed, and the 10x5 Shuttle run, where rural boys excelled. These findings suggest that younger children in Kosovo generally possess similar motor and functional abilities, as well as comparable anthropometric measures, regardless of their living area. However, urban boys tend to be slightly taller, heavier, and have longer arms and trunks, with less body fat compared to their rural peers. Conversely, rural boys demonstrated slightly better results in balance, repetitive abdominal and static arm strength, as well as aerobic power.

Eight-year-old boys show significant differences in longitudinal anthropometric measures, specifically body height and length of the sitting trunk (Table 2). Similar to the seven-year-olds (Table 1), there is also a difference between the groups in the 10x5 Shuttle run. Beyond these morphological measurements, urban boys are slightly heavier, this time with a greater fat mass compared to rural boys.

Table 1. T-test results between urban and rural, seven-year-old boys.

Variables	Urban		Rural		t-Value	p-Value
	Mean	SD	Mean	SD		
Body weight (kg)	27,13	14,39	25,50	7,16	0,720	0,476
Body height (cm)	124,94	5,24	124,00	6,57	0,792	0,431
The length of the sitting trunk (cm)	68,44	3,16	67,40	3,90	1,461	0,146
Arms length open (cm)	122,88	6,45	122,52	6,62	0,284	0,783
The triceps skinfold (mm)	8,90	3,56	8,90	5,08	0,000	1,000
Abdominal skinfold (mm)	6,88	4,91	9,22	9,56	-1,543	0,127
Subscapular skinfold (mm)	5,44	2,48	6,32	5,35	-1,057	0,294
Flamingo balance (sec)	11,46	8,35	11,70	8,39	-0,146	0,886
Plate tapping (n of taps)	20,01	3,34	55,79	25,52	-0,984	0,329
Sit-and-reach (n of repetitions)	36,10	5,93	36,24	5,22	-0,131	0,900
Standing broad jump (cm)	102,78	20,03	92,02	25,35	2,354	0,021*
Sit-ups in 30sc (n of repetitions)	14,48	3,33	14,36	4,88	0,142	0,886
Bent arm hang (sec)	8,11	8,06	9,48	10,80	-0,721	0,473
10x5 Shuttle run (sec)	21,38	1,26	20,36	2,73	2,401	0,018*
20m Beep test (level)	3,08	1,69	3,24	1,22	-0,522	0,603

Values are expressed as means and standard deviations (SD). An asterisk (*) indicates a significant difference.

Table 2. T-test results between urban and rural, eight-year-old boys.

Variables	Urban		Rural		t-Value	p-Value
	Mean	SD	Mean	SD		
Body weight (kg)	28,68	7,54	26,15	5,20	1,950	0,054
Body height (cm)	131,16	5,81	127,90	4,86	3,049	0,003*
The length of the sitting trunk (cm)	70,98	3,19	69,22	2,37	3,136	0,002*
Arms length open (cm)	126,88	6,53	125,32	5,50	1,291	0,199
The triceps skinfold (mm)	8,78	3,10	8,02	3,30	1,192	0,238
Abdominal skinfold (mm)	7,02	5,42	8,92	7,41	-1,463	0,146
Subscapular skinfold (mm)	5,84	3,82	5,36	2,16	0,775	0,442
Flamingo balance (sec)	9,22	8,27	9,22	6,49	0,000	1,000
Plate tapping (n of taps)	18,07	2,53	18,48	3,18	-0,711	0,480
Sit-and-reach (n of repetitions)	35,74	6,95	33,62	7,76	1,441	0,153
Standing broad jump (cm)	100,72	19,72	123,50	130,47	-1,222	0,225
Sit-ups in 30sc (n of repetitions)	12,96	3,65	11,90	3,95	1,393	0,166
Bent arm hang (sec)	15,29	15,87	11,54	11,16	1,374	0,174
10x5 Shuttle run (sec)	21,61	1,68	20,38	1,42	3,961	0,000*
20m Beep test (level)	2,86	0,95	3,10	0,89	-1,300	0,196

In terms of motor abilities, they excel in repetitive (legs and abdomen) and static arm strength. However, rural boys achieve better scores in aerobic and anaerobic power.

Further analysis of nine-year-old boys, as shown in Table 3, revealed significant differences in several variables: body weight, body height, sit-ups in 30 seconds, the 10x5 Shuttle run, and the 20m Beep test. As with younger age groups, rural boys displayed superior aerobic and anaerobic power. In this age category, rural boys outperformed their urban peers in almost all motor tests, with the exception of the Sit-and-reach. They also carried more fat mass compared to their urban counterparts. Urban boys, however, excelled in absolute morphological measures.

Slight indications of the prepubertal stage may be observed in Table 4, where rural boys appear to enter this phase slightly earlier. This is evidenced by noticeable weight gains, alignment of longitudinal

Table 3. T-test results between urban and rural, nine-year-old boys.

Variables	Urban		Rural		t-Value	p-Value
	Mean	SD	Mean	SD		
Body weight (kg)	36,26	10,33	30,48	8,15	3,111	0,002*
Body height (cm)	138,64	6,45	135,40	6,33	2,542	0,013*
The length of the sitting trunk (cm)	74,26	3,77	72,78	3,79	1,961	0,053
Arms length open (cm)	134,18	7,02	133,38	7,96	0,533	0,595
The triceps skinfold (mm)	9,58	4,95	9,66	5,02	-0,084	0,936
Abdominal skinfold (mm)	11,00	9,59	12,58	9,98	-0,815	0,422
Subscapular skinfold (mm)	6,46	4,17	7,18	5,95	-0,706	0,485
Flamingo balance (sec)	9,18	7,45	9,90	6,19	-0,537	0,600
Plate tapping (n of taps)	14,72	1,84	15,10	2,21	-0,939	0,356
Sit-and-reach (n of repetitions)	33,90	7,93	32,62	9,38	0,740	0,463
Standing broad jump (cm)	113,62	28,53	116,80	22,47	-0,620	0,537
Sit-ups in 30sc (n of repetitions)	12,78	5,33	15,26	4,07	-2,611	0,010*
Bent arm hang (sec)	11,57	12,47	15,74	32,08	-0,860	0,394
10x5 Shuttle run (sec)	20,37	1,89	19,49	1,67	2,480	0,015*
20m Beep test (level)	3,27	1,19	3,97	1,75	-2,342	0,021*

Table 4. T-test results between urban and rural, ten-year-old boys.

Variables	Urban		Rural		t-Value	p-Value
	Mean	SD	Mean	SD		
Body weight (kg)	27,59	6,08	37,48	12,69	-4,970	0,000*
Body height (cm)	140,36	6,18	140,78	6,43	-0,330	0,740
The length of the sitting trunk (cm)	75,46	4,02	74,52	3,96	1,188	0,241
Arms length open (cm)	135,68	6,99	140,12	8,06	-2,946	0,004*
The triceps skinfold (mm)	8,36	3,67	11,42	7,55	-2,585	0,011*
Abdominal skinfold (mm)	10,30	8,64	17,28	16,11	-2,704	0,008*
Subscapular skinfold (mm)	6,50	4,23	10,16	11,44	-2,122	0,036*
Flamingo balance (sec)	8,28	5,42	9,60	7,79	-0,981	0,328
Plate tapping (n of taps)	13,89	2,36	14,60	2,54	-1,445	0,152
Sit-and-reach (n of repetitions)	28,24	8,27	34,14	6,00	-4,089	0,000*
Standing broad jump (cm)	136,62	21,95	113,18	20,88	5,470	0,000*
Sit-ups in 30sc (n of repetitions)	14,12	5,02	15,14	5,81	-0,940	0,350
Bent arm hang (sec)	18,06	16,78	15,50	15,38	0,790	0,429
10x5 Shuttle run (sec)	19,31	1,20	19,19	1,70	0,410	0,685
20m Beep test (level)	3,90	1,10	3,67	1,42	0,880	0,379

morphological measures with those of the urban group, and significantly higher fat mass levels, characteristic of the prepubertal stage in the rural group. Rural boys exhibited a significantly greater arm span, although their trunks were slightly shorter. Motor abilities varied, but significant differences were observed in the Sit-and-reach, with the rural group performing better, and in the Standing broad jump, where the urban group excelled. Urban boys demonstrated better aerobic results and relative static strength, likely due to their lighter body weight.

Results from Table 5 suggest the possible onset of the prepubertal stage among urban boys, as anthropometric differences have largely diminished, except for the abdominal skinfold. Significant differences were noted in motor variables: the urban group again scored higher in the Standing broad jump, while the rural group excelled in balance and repetitive strength exercises for the abdomen and legs. Additionally, rural boys demonstrated significantly greater aerobic capacities. This is the first instance where the urban group exhibited

Table 5. T-test results between urban and rural, eleven-year-old boys.

Variables	Urban		Rural		t-Value	p-Value
	Mean	SD	Mean	SD		
Body weight (kg)	41,63	11,03	40,16	10,79	0,681	0,501
Body height (cm)	147,26	5,72	144,86	7,03	1,876	0,064
The length of the sitting trunk (cm)	77,80	3,25	76,56	3,96	1,715	0,090
Arms length open (cm)	145,08	7,45	144,20	7,38	0,594	0,554
The triceps skinfold (mm)	11,12	4,78	11,34	6,96	-0,187	0,854
Abdominal skinfold (mm)	12,82	8,61	20,40	15,52	-3,029	0,003*
Subscapular skinfold (mm)	7,52	4,51	9,84	7,94	-1,800	0,075
Flamingo balance (sec)	7,18	5,73	10,24	7,06	-2,380	0,019*
Plate tapping (n of taps)	13,32	2,64	14,03	2,06	-1,500	0,137
Sit-and-reach (n of repetitions)	30,94	8,35	34,62	7,10	-2,379	0,020*
Standing broad jump (cm)	123,84	15,89	112,62	26,80	2,558	0,012*
Sit-ups in 30sc (n of repetitions)	14,60	5,23	16,58	3,56	-2,211	0,029*
Bent arm hang (sec)	15,06	18,15	15,89	17,12	-0,242	0,814
10x5 Shuttle run (sec)	19,09	1,39	19,13	1,81	-0,111	0,912
20m Beep test (level)	3,43	1,21	4,24	1,66	-2,811	0,006*

superior anaerobic power.

Discussion

This study aimed to determine possible differences in EUROFIT scores between rural and urban male children in Kosovo aged 7 to 11 years and to identify underlying factors beyond these differences. Initial findings reveal that while some motor and anthropometric measures showed significant differences, others did not, indicating a complex interaction of environmental and other factors. Furthermore, differences in specific tests like the Standing broad jump and 10x5 Shuttle run suggest varying developmental trends between the two groups.

The related study [9] conducted on schoolchildren aged 8-11 in two different environments in Turkey, although not age-stratified, found significant differences only in basic anthropometry and certain fitness tests (Sit-ups in 30sec and Bent arm hang). Compared to their Turkish peers, children in Kosovo show partial similarities, especially in the variability of height-related measures and the absence of differences in certain motor skills, while other data differ across generations.

The study with a protocol similar to ours [10] was previously conducted in North Macedonian schools, involving over 5,000 participants (average age 9.94 ± 2.41 years). It revealed that children from rural environments outperformed their urban peers in cardiorespiratory fitness, muscle fitness of the upper and lower extremities, and displayed better coordination, speed, and agility. Although such results might be expected, our findings confirm them only partially—specifically in the prepubertal stage, but not during the middle childhood phase. These differences may be attributed to the distinct environments experienced by younger children in North Macedonia compared to Kosovo. Additionally, an analysis [11] of 11 and 12-year-old schoolchildren in Albania, a neighboring country, revealed similar trends in physical fitness and anthropometric characteristics among prepubertal children.

This study provides better insight into the generational changes among male children in different environments. As noted in the results, urban children during middle childhood tend to be slightly taller, heavier, and longer, possibly due to easier access to various kinds of processed and unprocessed food, which boosts their growth from an early age. Urban children are also slightly stronger at these ages, which could be attributed to more frequent participation in organized activities under professional supervision, as well as their diet. An interesting study [12] examined the impact of family background on physical health in rural areas, finding that lower educational levels of parents and the professional occupation of the mother were correlated with higher body mass index in children. Physical condition appears to be influenced by the educational level and professional occupation of the family, particularly the mother. These factors may also contribute to the lack of organized supervision and training of children through their early and middle childhood in rural areas of Kosovo. It is important to note the earlier entry of rural boys into the prepubertal stage, which could be explained by their continuous physical activity and better access to nature, whereas urban boys tend to become more sedentary as they age. Many factors may influence

such behavior, primarily video games, uncontrolled internet access, increasing school activities, overly protective parents, and more. Rural boys not only maintain their physical activity levels over the years but also enhance them as they grow older and begin assisting in various rural activities, which often require different forms of strength. Therefore, the observed differences in motor abilities in older rural-urban groups are expected. However, these differences seem to be even more pronounced in highly developed societies, as evidenced in Australia [13].

Researchers in Scotland [14] found that rural children spent an average of 14 minutes less being sedentary and 13 minutes more engaging in light-intensity activity per day. These figures are significant when considered cumulatively. However, in some instances, urban preadolescent children exhibit better levels of physical fitness than their rural peers, as seen in Croatia [15], and urban children in the US have a lower risk of obesity [16]. This indicates that such trends vary across nations, and each country and region must be evaluated independently. Furthermore, cardio-metabolic variables tend to increase with age. For example, during puberty, boys experience accelerated skeletal growth and muscle mass increases, which enhance maximum oxygen supply and improve endurance and sports performance [17]. As both groups enter puberty (Table 5), anthropometric differences gradually diminish, yet the rural group continues to excel in motor and functional abilities. There is an increasing concern for the physical fitness of urban prepubertal and pubertal children. One potential solution is school-based sports activities, which can significantly boost daily physical activity in urban settings [18]. Other strategies include ongoing education for parents and children about the importance of physical health and its impact on quality of life.»

The limitations of this study include its focus on a specific sample of participants, as it exclusively encompasses male children from Kosovo and does not include females. Future research should explore the trends in EUROFIT testing across generations in rural and urban areas for female samples, as well as similar samples in other regions and countries.

Conclusions

This study explores differences in growth and abilities between rural and urban male children, focusing on age-stratified analysis. The results suggest that urban children initially have better access to organized physical activities and varied diets, which may enhance physical power, although these diets might be less healthy. As schooling begins, the rural environment seems more conducive to healthy growth and the development of abilities in boys. Thus, it is important for urban children to maintain regular organized physical activities throughout their schooling to match the motor and functional abilities of their rural peers. Over time, morphological traits tend to equalize between these groups as they approach the prepubertal stage.

Highlights

- Urban children display slightly better physical fitness during middle childhood, whereas rural children excel as they approach the prepubertal stages.
- Despite fewer opportunities for organized sports and access to less-caloric but healthier diets, rural children tend to demonstrate superior motor abilities compared to their urban peers.
- Skeletal growth in the studied age groups is influenced by factors unrelated to their rural or urban environments as they near puberty.

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ORIGINAL ARTICLE

Acute effects of whole-body vibration during dynamic lunge movement on jump and sprint performances

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim: The aim of this study was to examine the acute effects of whole-body vibration applied to the dominant and non-dominant leg during repetitive lunge movements on jump and sprint performance.

Material and Methods: Thirty-five male students from the Faculty of Sport Sciences voluntarily participated in the study. Participants performed squat jumps and countermovement jumps, and a 30-m sprint test on a non-motorized treadmill as pre- and post-tests. Participants were divided into the experimental group (n = 19, age: 22.0 ± 1.9 years, height: 177.7 ± 6.3 cm, body weight: 75.5 ± 12.6 kg) and the control group (n = 16, age: 21.9 ± 1.9 years, height: 173.4 ± 4.1 cm, body weight: 67.7 ± 7.1 kg). In the experimental group, a whole-body vibration of 50 Hz frequency and 4 mm amplitude was continuously applied to the dominant front leg. This was done on the whole-body vibration platform for 60 seconds throughout the repetitive lunge movement. At the end of the time, the leg was changed, and whole-body vibration was applied to the non-dominant leg using the same method. The control group performed the same movement without whole-body vibration. Pre- and post-test results were compared with an independent sample t-test within the group and a paired sample t-test between the groups. The statistical significance level was determined as $p \leq 0.05$.

Results: The experimental group showed statistically significant pre-test and post-test differences in 30-m sprint power, non-dominant leg power, and non-dominant leg horizontal force parameters ($p < 0.05$, $p < 0.01$, and $p < 0.05$, respectively). It was determined that performing dynamic lunge movements with the dominant and non-dominant legs using whole-body vibration significantly increased mean power and non-dominant leg horizontal force.

Conclusions: The acute effect on power, particularly on non-dominant leg power and non-dominant leg horizontal force during the 30-m sprint, was significant. This showed that whole-body vibration can be used as a short-term training method. In studies aiming to determine the acute and chronic effects of exercises with whole-body vibration on various performance parameters, it is important to focus on the frequency and amplitude differences in certain protocols.

Keywords: whole-body vibration, sprint, vertical force, horizontal force, power

Introduction

In training science, whole-body vibration (WBV) during static or dynamic movements is frequently used as a training method to increase physical performance. It was first used for sports in Russia in the 1980s to give their Olympic team a competitive advantage by helping them speed up their recovery [1, 2]. Generally, WBV is applied before exercise on a special platform to prevent muscular fatigue [3]. It is performed at various amplitudes (1-10 mm) and frequencies (1-60 Hz) [4] in two ways: the athlete's whole body is on a platform, or vibration is applied to a part of their body [5]. With the increasing popularity of this novel approach in sports science, the aim is to enhance neuromuscular strength and power [6].

Low-frequency vibrations can simultaneously stimulate joints, tendons, and muscles [7]. Meanwhile, muscle spindles are stimulated through short and fast mechanical vibrations, creating a type of reflex response called a tonic vibration reflex. As a result of this reflex response, there is an increase in muscle tone [8]. When WBV is applied to the body, muscles and tendons, due to their flexible structure, act as spring-like elements in the release mechanism of stored energy [9]. Additionally, in WBV, the body's soft tissues, muscles, bones, and joints can tolerate, overcome, and absorb mechanical energy up to a certain point [10]. WBV causes reactive forces by transferring energy to the whole body

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or to a specific part of the body. These forces have the potential to be beneficial but also potentially harmful [11]. Based on this idea, it has been predicted that the use of WBV in training science may be beneficial for performance improvement [12, 13]. Repetitive muscle contractions performed with WBV for 20 seconds to 1 minute at a frequency of >20 Hz, combined with strength training, can improve maximal voluntary contraction [10]. This development is caused by motor unit synchronization and the firing of previously inactive motor units [2].

In the study [14], WBV training was applied to trained and untrained individuals at different exercise intensities (20, 35, 50 Hz and 3 mm amplitude) to determine its acute effect on the lower extremities. Following this, squat jump (SJ) and countermovement jump (CMJ) were tested. Improvement was observed in both groups at a frequency of 50 Hz, whereas no improvement was seen at frequencies of 20 and 35 Hz. Consequently, it was concluded that working with 50 Hz is necessary to determine the effects of traditional explosive strength training. This conclusion was supported by Feland et al.'s [15] study, which found that WBV, including 10 intervals (26 Hz and 3.6 mm) of 60 seconds in a half squat followed by 60 seconds of rest, had no effect on CMJ.

Involuntary contractions can be increased with vibration training [16]. WBV training increased the activation of the leg muscles (rectus femoris, vastus lateralis, vastus medialis, and gastrocnemius) [4]. Peak power values increased after concentric contractions due to squat training performed with vibration [3]. Since CMJ increased after WBV training, WBV training could be a potential warm-up exercise to enhance CMJ [17]. Dallas et al. [18] also found an increase in SJ and CMJ with WBV training.

Studies have shown that WBV training has positive effects on performance [6, 18, 19, 20], but there are also studies indicating that it has negative or no effects [11, 21, 22]. It is believed that new studies using WBV at different frequencies, various body positions, and movements are needed to obtain more detailed information about the effects of WBV applications.

Although many studies [6, 23, 24, 25] have examined the acute effects of WBV during dynamic movements on SJ and CMJ heights and sprint time, the varying results regarding SJ and CMJ jump heights and sprint time are attributed to differences in vibration parameters. These parameters include amplitudes between 0.83-4.00 mm, frequencies between 20-50 Hz, application times between 20-90 seconds, repetitions between 1-10, and movement variabilities. Based on these studies, determining the specific effects of WBV on the dominant leg (DL) and non-dominant leg (NDL) during dynamic lunge movements, particularly for leg muscle performance improvement, will inform new training protocols for jumping and sprinting. It will also guide future studies on the chronic effects of WBV. Therefore, the aim of this study was to examine the acute effects of WBV applied to the DL and then the NDL during repetitive lunge movements on jump and sprint performances.

Material and Methods

Participants

Forty male students from the Faculty of Sports Sciences, aged between 18 and 22, participated in this study. These students had no experience with WBV training and were physically active at an easy-to-medium level (≤3 aerobic sessions per week). G*Power 3.1.9.7 analysis indicated that a minimum of 38 participants (19 in each group) was necessary for the study. The analysis was based on a required power (1- β) of .80, a type I error or alpha level, α = .05, and an effect size (d) of .80. The study utilized a non-crossover experimental design, with subjects randomly divided into two groups: the experimental group (EG) (n = 19, age: 22.0 ± 1.9 years, height: 177.7 ± 6.3 cm, body weight: 75.5 ± 12.6 kg) and the control group (CG) (n = 16, age: 21.9 ± 1.9 years, height: 173.4 ± 4.1 cm, body weight: 67.7 ± 7.1 kg).

Two participants from the EG and three participants from the CG were excluded from the study due to missing values. Participants were free to discontinue the study at any time. They were asked to maintain their normal dietary intake, avoid any strenuous exercise in the 48 hours before the experimental sessions, and abstain from smoking, alcohol, and caffeine consumption for 24 hours before all tests. Participants were randomly assigned to the test protocols.

Written informed consent was obtained from the participants in accordance with the principles of the Helsinki Declaration after the procedures and potential risks had been explained to them. Ethical Committee approval (Code number: Istanbul Nisantasi University n.2022/24) was also obtained.

Research Design

Participants were assigned to the measurement and testing protocols using a simple random method. Each participant performed a 30-m sprint on a non-motorized treadmill and jump tests before and after the vibration applied during repetitive lunge movements with the DL and then the NDL. Before starting the measurements and tests, each device was calibrated. Each participant underwent tests and the vibration protocol for trial and familiarization 3-7 days before the study. The "Waterloo Footedness Questionnaire-Revised" by Elias and Bryden [26], adapted to Turkish by Özsu [27], was used to determine the DL and NDL.

The participants warmed up for 10 minutes in their sportswear, which included jogging,

stretching, and exercise movements. As pre-tests, they performed two 30-m sprint tests with 3-minute intervals and vertical jump tests consisting of SJ and CMJ after 90 seconds of passive rest, as stated by Kacoglu and Kale [28]. Each jump test was performed twice with 30 seconds of passive rest between attempts. Each participant rested passively between the two jump tests. Before the post-tests, during the repetitive dynamic lunges, the DL and then the NDL were placed on the vibration platform, and the vibration was applied to the sole of the foot for 1 minute each, totaling 2 minutes in the EG. The CG performed the same lunges without WBV. The two 30-m sprint and jump tests were repeated with the same protocols after a 90-second passive rest following the dynamic lunges.

Body Weight and Height Measurements

Body weight was measured using an electronic laboratory scale (Seca, Vogel & Halke, Hamburg) with an accuracy of 0.1 kg, and height was measured using a wall-mounted stadiometer (Holtain, UK) with an accuracy of 0.01 mm, according to Lohman et al. [29].

Sprint Test

Subjects participated in a 2x30 m sprint test with a 3-minute interval on a non-motorized computer-assisted treadmill (Woodway Force 3.0, Woodway Inc., USA) after a 10-minute warm-up consisting of light running, stretching, and mobility exercises. Before testing, the horizontal force (HF) strain gauge was adjusted parallel to the treadmill at waist level. The best 30 m sprint result was statistically analyzed. Thirty-meter sprint speed was calculated using the mean velocity (Vmean) formula: Vmean = distance (d) / time (t), expressed in $m \cdot s^{-1}$. During the 30 m sprint, HF and vertical force (VF) data were recorded to a computer at 200 Hz.

Mean HF (HF_{mean}) was calculated with 30 m sprint total HF/30m sprint total stride number formula in terms of Newton. Mean VF (VF_{mean}) was calculated with 30 m sprint total VF/30m sprint total stride number formula in terms of Newton. Same calculation method was used for all other sprint parameters of both legs that are mean stride frequency (SF_{mean}), mean stride length (SL_{mean}), mean work (W_{mean}) and mean power (P_{mean}), and also DL and NDL that are dominant leg SF (SF_{DL}), non-dominant leg (SF_{NDL}), dominant leg SL (SL_{DL}), non-dominant leg SL (SL_{NDL}), dominant leg HF (HF_{DL}), non-dominant leg HF (HF_{NDL}), dominant leg VF (VF_{DL}), non-dominant leg VF (VF_{NDL}), dominant leg W (W_{DL}), non-dominant leg W (W_{NDL}), dominant leg P (P_{DL}), non-dominant leg P (P_{NDL}).

Jump Tests

SJ and CMJ tests were performed using the OptoJump™ (Microgate, Bolzano, Italy), which records with 1 ms accuracy. One of the two parallel bars of the device, placed on the ground and connected to the computer via a data-transmitting cable, served as the transmitter unit emitting infrared light 0.003 m above the ground. The other bar functioned as the receiver unit. Each participant performed the SJ and CMJ after taking a fixed position for jumping between these two parallel bars. When the participant's feet interrupted the infrared light during the jump, the timer on the unit was triggered and stopped when the feet returned to the starting position after the jump. The time between taking off from the ground and landing back on the ground after the jump was considered the flight time.

The flight time of the SJ and CMJ was transferred to the computer, and the jump heights were calculated using the OptoJump™ software. After each jump test, participants rested for 60 seconds. For each jump test, two trials were performed with 30-second rest breaks, and the highest jump height was used for statistical evaluation. As suggested by Bosco and Komi [30], the SJ was performed on the ground between two parallel bars, with feet shoulder-width apart, eyes focused forward, hands on the waist, and jumping vertically from a ~90° fixed squat position. The CMJ was performed on the ground between the same two parallel bars, with feet shoulder-width apart, eyes focused forward, hands on the waist, squatting from the standing position to a ~90° squat position as quickly as possible, and then jumping vertically.

WBV

First, the mat on the WBV device (Power Plate, pro5, AIRdaptive, London, UK) was removed to prevent it from absorbing the vibration. Each participant in the EG was prepared according to Kale [31]: without shoes, with hands on the waist and torso upright, standing on the phalanges of the DL. After positioning their knees in a flexed position between approximately 110-130°, a repetitive dynamic lunge movement was performed, extending until the knees reached 180°. During the repetitive dynamic lunge movement, WBV was applied to the DL for 1 minute at a frequency of 50 Hz and an amplitude of 4 mm. To ensure the foot on the WBV device maintained a 90° joint angle, each participant placed their other foot on a stand of the same height outside the WBV device. Immediately after this period, the leg was changed, and WBV was applied to the NDL using the same method.

Statistical Analyses

Data analysis was conducted using Jamovi (2.3.28.0, Stats Open Now). All pre-test parameters of the participants were determined to be normally distributed by Skewness-Kurtosis analysis, and they were divided into two groups, EG and CG, using a simple random method. The same statistical analyses showed that the pre-test parameters of EG and CG were normally distributed. Pre-test jump

and 30 m sprint parameters related to the NDL and DL were normally distributed, except for HF_{NDL} and HF_{DL}. Specifically, pre-test parameters were normally distributed except for HF_{DL} in EG and HF_{NDL} in CG. Pre- and post-test results between the groups were compared using an independent sample t-test. Pre- and post-test results within the groups were compared using a paired sample t-test. The Mann-Whitney U test was used for pre-test and post-test comparisons between the two groups for HF_{NDL} and HF_{NDL}, which did not show normal distributions in the pre-tests, and the Wilcoxon Signed Rank test was used for pre- and post-test comparisons within the two groups. Statistical significance was determined by an alpha level of $p \leqslant 0.05$. Cohen's d effect size (ES) was calculated from the mean and standard deviation and classified as: trivial (<0.20), small (0.20 to 0.49), medium (0.50 to 0.79), or large (⩾0.80) as described by Wassertheil and Cohen [32].

Results

All results are presented in Tables 1, 2, 3, 4, and 5.

There were no significant statistical pre- and post-test differences between and within 2 groups in SJ and CMJ parameters (Table 1).

As seen in Table 2, there were statistically significant differences in the VF and P parameters between the groups in the 30 m sprint pre-tests [ES: 0.89 (large), $p < 0.01$ and ES: 0.76 (moderate), $p < 0.05$, respectively]. In the post-tests, statistically significant differences were also found between the groups in the same parameters [ES: 1.0 (large), $p < 0.01$ and ES: 0.88 (large), $p < 0.05$, respectively]. In pre- and post-test comparisons within the groups, only the P parameter showed a statistically significant difference in the EG [ES: 0.52 (moderate), $p < 0.05$].

As seen in Table 3, the non-parametric comparisons between groups for the HF parameter, which did not show a normal distribution in the 30 m sprint, revealed significant differences in the pre-tests [ES: 0.49 (low), $p < 0.01$] and in the post-tests [ES: 1.14 (large), $p < 0.001$]. There were no statistically significant pre- and post-test differences within the two groups for the HF parameter.

Table 4 showed that there were significant statistical pre-test differences in VF_{NDL}, VF_{DL}, and P_{DL} between EG and CG ($p < 0.01$, $p < 0.05$, and $p < 0.01$, respectively). VF_{NDL}, VF_{DL}, P_{NDL}, and P_{DL} had significant post-test differences between EG and CG ($p < 0.05$, $p < 0.01$, $p < 0.05$, and $p < 0.05$, respectively). Pre-test and post-test P_{BOB} comparisons within the groups demonstrated a statistically significant difference in EG ($p < 0.01$).

As seen in Table 5, there was no statistically significant HF_{NDL} difference in the pre-test in the non-parametric comparisons between groups, but there was a statistically significant difference in the post-test comparison [ES: 0.41 (small), $p < 0.05$]. In non-parametric comparisons of HF_{DL} between groups, a statistically significant difference was found in the pre-tests [ES: 0.61 (medium), $p < 0.01$] and in the post-tests [ES: 0.43 (low), $p < 0.05$]. HF_{NDL} showed a statistically significant difference in EG [ES: -0.71 (medium), $p < 0.01$] for pre-test and post-test non-parametric comparisons within the groups.

Discussion

The aim of this study was to examine the acute effects of vibration applied to the DL and then the NDL during repetitive lunge movements on jump and sprint performances. In the literature, only one study [30] investigated the acute effects of dynamic lunge movement with NDL WBV (4 mm, 50 Hz, 60 s) on sprinting and jumping in 38 physically active males who exercised at least three times a week from the Faculty of Sports Sciences. In the study by [30], there was an acute statistical decrease ($p < 0.05$) in the performance of 30 m sprints, SJ, and CMJ after dynamic lunge movement performed with WBV only on the NDL. In contrast, the current study found no decrease in these variables after the lunge movement performed with WBV on both the DL and NDL.

Table 1. Mean ± SD values and pre- and post-test comparisons of jump parameters for DG (n= 19) and CG (n= 16)

Parameters	Group	Pre	Post	ES [95% CI]	Inference
SJ (cm)	EG	35.4 ± 7.4	35.9 ± 8.2	0.22 [-0.67, 0.23]	Small
	CG	32.5 ± 4.5	32.8 ± 4.4	0.16 [-0.65, 0.32]	Trivial
	ES [95% CI]	0.35 [-0.15, 0.85]	0.39 [-0.12, 0.89]		
	Inference	Small	Small		
CMJ (cm)	EG	38.3 ± 7.8	38.4 ± 8.4	0.04 [-0.49, 0.40]	Trivial
	CG	35.01 ± 4.4	35.5 ± 4.3	0.36 [-0.86, 0.14]	Small
	ES [95% CI]	0.33 [-0.17, 0.83]	0.33 [-0.18, 0.83]		
	Inference	Small	Small		

SJ: Squat jump; CMJ: Countermovement jump; EG: Experimental group; CG: Control group; Mean ± Sd: Mean ± Standard deviation; ES [%95 CI]: Effect size [95% Confidence interval].

Table 2. Mean ± SD values and pre- and post-test comparisons of 30 m sprint parameters for DG (n= 19) and CG (n= 16)

Parameters	Group	Pre	Post	ES [95% CI]	Inference
t (s)	EG	6.43 ±1.6	6.47 ± 1.6	0.12 [-0.57, 0.32]	Trivial
	CG	5.51 ±1.6	5.59 ± 1.78	0.22 [-0.72, 0.27]	Small
	ES [95% CI]	0.56 [-0.13, 1.24]	0.52 [-0.17, 1.19]		
	Inference	Moderate	Moderate		
TS (number)	EG	36.05 ± 5.38	36.57 ± 6.34	0.12 [-0.57, 0.32]	Trivial
	CG	38.62 ± 5.78	39.37 ± 5.14	0.13 [-0.62, 0.36]	Trivial
	ES [95% CI]	0.46 [-1.13, 0.22]	0.47 [-1.15, 0.21]		
	Inference	Small	Small		
SF (Hz)	EG	5.99 ± 1.22	6.21 ± 1.09	0.24 [-0.69, 0.21]	Small
	CG	6.38 ± 1.10	6.52 ± 0.86	0.14 [-0.63, 0.34]	Trivial
	ES [95% CI]	0.32 [-0.99, 0.35]	0.31 [-0.98, 0.36]		
	Inference	Small	Small		
SL (m)	EG	0.85 ± 0.12	0.84 ± .14	0.06 [-0.39, 0.51]	Trivial
	CG	0.79 ± 0.12	0.77 ± .10	0.17 [-0.32, 0.66]	Trivial
	ES [95% CI]	0.46 [-0.22, 1.13]	0.54 [-0.14, 1.23]		
	Inference	Small	Moderate		
VF (N)	EG	786.1 ± 153.1	796.7 ± 158.7	0.30 [-0.76, 0.15]	Small
	CG	673 ± 84.3¥¥	665.7 ± 85.5¥¥	0.15 [-0.34, 0.64]	Trivial
	ES [95% CI]	0.89 [0.15, 1.6]	1.00 [0.25, 1.70]		
	Inference	Large	Large		
P (W)	EG	725.7 ± 96.6	761 ± 133.9*	0.52 [-0.99, -0.03]	Moderate
	CG	664.2 ± 54.8¥	663.7 ± 71.9¥	0.01 [-0.47, 0.50]	Trivial
	ES [95% CI]	0.76 [0.04, 1.46]	0.88 [0.14, 1.59]		
	Inference	Moderate	Large		

EG: Experimental group; CG: Control group; Mean ± Sd: Mean ± Standard deviation; ES [%95 CI]: Effect size [95% Confidence interval]; t: time; TS: Total stride; SF: Stride frequency; SL: Stride length; HF: Horizontal force; VF: Vertical force; P: Power; *: p<0.05 within the groups; ¥: p<0.05 between the groups; ¥¥: p<0.01 between the groups.

Table 3. Mean ± SD values and pre- and post-test non-parametric comparisons of HF parameters in 30 m sprint test for DG (n= 19) and CG (n= 16)

Parameters	Group	Pre	Post	ES	Inference
HF (N)	**EG**	153.4 ± 8.61	160.1 ± 15.9	-0.58	Moderate
	CG	145.7 ±6.12¥¥	145.7 ±6.80¥¥	0.07	Trivial
	ES	0.49	1.14		
	Inference	Small	Large		

EG: Experimental group; CG: Control group; Mean ± Sd: Mean ± Standard deviation; ES [%95 CI]: Effect size [95% Confidence interval]; HF: Horizontal force; ¥¥: p<0.01 between the groups; ¥¥¥: p<0.001 between the groups.

Many studies have investigated the effects of WBV on increasing muscle activity in both acute and chronic conditions, particularly in vertical jump [33, 34], CMJ [14, 17, 34, 35], power and gross motor learning [36], and squats [37, 38, 39]. The main factors contributing to the varying results in the acute and chronic effects of WBV exercises on performance parameters include amplitude and frequency intervals, type of WBV, application procedures, training volume and intensity, exercise protocols, and participant characteristics [35].

The study by [36] stated that WBV combined

Table 4. Mean ± SD values and pre- and post-test non-parametric comparisons of 30 m sprint DL and NDL parameters for DG (n= 19) and CG (n= 16)

Parameters	Group	Pre	Post	ES [95% CI]	Inference
SF_{NDL} (Hz)	EG	6.05 ± 1.14	6.23 ± 1.10	0.25 [-0.70, 0.20]	Small
	CG	6.36 ± 1.15	6.44 ± .90	0.08 [-0.57, 0.40]	Trivial
	ES [95% CI]	0.27 [-0.40, 0.93]	0.20 [-0.46, 0.86]		
	Inference	Small	Small		
SF_{DL} (Hz)	EG	6.20 ± 1.10	6.18 ± 1.13	0.02 [-0.42, 0.47]	Trivial
	CG	6.39 ± 1.09	6.59 ± .92	0.17 [-0.66, 0.31]	Trivial
	ES [95% CI]	0.17 [-0.49, 0.84]	0.39 [-0.29, 0.60]		
	Inference	Trivial	Small		
SL_{NDL} (m)	EG	0.83 ± 0.12	0.82 ± 0.13	0.11 [-0.33, 0.56]	Trivial
	CG	0.78 ± 0.12	0.76 ± 0.11	0.16 [-0.33, 0.65]	Trivial
	ES [95% CI]	0.35 [-1.02, 0,32]	0.42 [-1.09, 0.26]		
	Inference	Small	Small		
SL_{DL} (m)	EG	0.83 ± 0.14	0.83 ± 0.14	0.01 [-0.43, 0.46]	Trivial
	CG	0.78 ± 0.12	0.75 ± 0.10	0.23 [-0.26, 0.72]	Small
	ES [95% CI]	0.43 [-1.10, 0.25]	0.63 [-1.33, 0.07]		
	Inference	Small	Moderate		
VF_{NDL} (N)	EG	758 ± 178	806 ± 206	0.30 [-0.76, 0.15]	Small
	CG	577 ± 140¥¥	666 ± 136¥	0.49 [-10.1, 0.03]	Small
	ES [95% CI]	1.11 [-1.87, -0.32]	0.78 [-1.49, -0.05]		
	Inference	Large	Moderate		
VF_{DL} (N)	EG	865 ± 160	826 ± 173	0.22 [-0.23, 0.68]	Small
	CG	749 ± 145¥	664 ± 131¥¥	0.51 [-0.01, 0.20]	Moderate
	ES [95% CI]	0.75 [-1.46, -0.02]	1.03 [-1.78, -0.26]		
	Inference	Moderate	Large		
P_{NDL} (W)	EG	701 ± 106	773 ± 162**	0.66 [-1.15, -0.15]	Moderate
	CG	669 ± 87	670 ± 97¥	0.01 [-0.50, 0.47]	Trivial
	ES [95% CI]	0.32 [-0.99, 0.35]	0.74 [-1.45, -0.01]		
	Inference	Small	Moderate		
P_{DL} (W)	EG	750 ± 97	748 ± 149	0.01 [-0.43, 0.46]	Trivial
	CG	659 ± 100¥¥	656 ± 80¥	0.02 [-0.46, 0.51]	Trivial
	ES [95% CI]	.92 [-1.65, -0.16]	0.75 [-1.45, -0.02]		
	Inference	Large	Moderate		

EG: Experimental group; CG: Control group; Mean ± Sd: Mean ± Standard deviation; ES [%95 CI]: Effect size [95% Confidence interval]; SFNDL: Non-dominant leg stride frequency; SFDL: Dominant leg stride frequency; SLNDL: Non-dominant leg stride length; SLDL: Dominant leg stride length; HFNDL: Non-dominant leg horizontal force; HFDL: Dominant leg horizontal force; VFNDL: Non-dominant leg vertical force; VFDL: Dominant leg vertical force; PNDL: Non-dominant leg power; PDL: Dominant leg power; **: $p<0.01$ within the groups; ¥ $p<0.05$ between the groups; ¥¥: $p<0.01$ between the groups.

with isometric squats is sufficient to induce post-activation potentiation (PAP), as indicated by a significant increase in maximal voluntary contraction (MVC) peak force immediately post-exercise. These results were supported by [40], which found that WBV causes a decrease in the excitation threshold of the central and peripheral nervous system, increasing the preferential recruitment of fast-twitch fibers. However, it was explained that the mechanism for this increase in peak force is unclear, as no changes in muscle activation or motor neuron excitability were observed. Another study [41] speculated that WBV for more than 1 minute may cause fatigue due to excessive contraction of the extrafusal fibers caused by constant muscle spindle firing, whereas WBV up to 1 minute may stimulate the gamma

Table 5. Mean ± SD values and pre- and post-test non-parametric comparisons of HFNDL and HFDL parameters in 30 m sprint test for DG (n= 19) and CG (n= 16)

Parameters	Group	Pre	Post	ES	Inference
HF_{NDL} (N)	EG	148 ± 11	163 ± 21**	-0.71	Moderate
	CG	147 ± 15	147 ± 15¥	0.03	Trivial
	EB	0.09	0.41		
	Inference	Trivial	Small		
HF_{DL} (N)	EG	158 ± 11	157 ± 24	0.19	Trivial
	CG	145 ± 18¥¥	144 ± 12¥	-0.12	Trivial
	ES	0.61	0.43		
	Inference	Moderate	Small		

EG: Experimental group; CG: Control group; Mean ± Sd: Mean ± Standard deviation; ES [%95 CI]: Effect size [95% Confidence interval]; HFNDL: Non-dominant leg horizontal force; HFDL: Dominant leg horizontal force; **: p<0.05 within the groups; ¥: p<0.05 between the groups; ¥¥: p<0.01 between the groups.

motor neurons just enough to increase peak force. In contrast, [17] found no significant differences in isometric squat peak force immediately after WBV. Additionally, studies [42] indicated that isometric squats with WBV resulted in significant decreases in muscle force output, muscle activation, and vertical jump performance after WBV.

In the study by [43], involving 40 healthy adults, WBV combined with 12-week resistance exercises resulted in a statistically significant increase in knee extension isometric strength and CMJ. Resistance exercises combined with WBV for a total of 18 sessions, 3 days a week for 6 weeks, significantly increased electromyography activity ($p < 0.05$), indicating that resistance exercises combined with WBV can be used to enhance neuromuscular activity [44]. The supportive effect produced by WBV and resistance training is thought to be due to the resulting tonic vibration reflex [45]. This reflex allows for greater muscle contractions, which may provide a greater stimulus for the adaptation of muscle strength and power. The repetitive stretch-shortening cycle during dynamic lunges stiffened the muscle-tendon unit [44]. Changes in leg muscle activity that occur with WBV during dynamic lunges help to increase the voluntary muscle damage that occurs during the eccentric phase of these movements [46]. Since the main principle of WBV is to create enough vibration to overload the muscle-tendon complex, an increase in force in the overloaded muscle is the expected result. In the current study, although there were no statistically significant differences in SJ and CMJ in the EG between pre-tests and post-tests, there was a slight increase in SJ and CMJ in the post-tests. The results of this study on the acute effects of strength exercises with WBV are consistent with those of [44]. The results of this study might differ from previous findings due to differences in participant characteristics and exercise protocols.

Six weeks of WBV can significantly improve plantar flexion strength in young healthy individuals, but the mechanisms supporting this result are currently unclear, necessitating further studies [47]. In the study by [48], a static (30 s) and dynamic (15 repetitions in 30 s) heel lift exercise was applied to one leg at a frequency of 35 Hz and an amplitude of 2-4 mm, 72 hours apart, on individuals without a history of orthopedic medical injury who use their right leg dominantly. They found that static and dynamic heel lift exercises combined with acute WBV have a positive acute effect on mediolateral posture control during a single-leg stance. WBV leads to increased neuronal excitability in the corticospinal pathway, which may originate in the cortical, subcortical, or spinal neurons, coupled with inhibition of the reflex spinal pathway [49]. For this reason, Folland and Williams [50] stated that muscle strength and power may be affected by changes in the muscle activity of other agonist muscles or changes in other aspects of muscle activation, including changes in relative agonist-antagonist activities and/or changes in coordination and learning. In the present study, the dynamic lunge movement performed with DL and NDL with WBV increased PNDL and HF_{NDL} statistically significantly, supporting the results of studies [47, 48, 50].

The study by [51] compared the effectiveness of two WBV protocols with equal training volume but different training frequencies on body composition and physical fitness. Participants were divided into three equal groups: a 3-days-a-week WBV group, a 5-days-a-week WBV group, and a control group. Both WBV groups followed a 10 x 1-minute protocol for each exercise session, which included 1 minute of WBV application (25-35 Hz, 4-6 mm) followed by 1 minute of rest. A statistically significant increase in maximum power ($p = 0.016$) was found in the 5-days-a-week WBV group. Similarly, SJ showed a statistically significant increase ($p < 0.01$) in both the 3-days-a-week and 5-days-a-week WBV groups. As a result, an intensified weekly WBV protocol was found to be more effective in improving lower

extremity strength and power in young active individuals. It was observed that there was no significant effect on anaerobic power in the lower frequency training group compared to the higher frequency group. The results indicated that WBV performed 3 or 5 days a week increased SJ. Although there was no statistically significant increase in the current study, the increase in SJ from 35.4 ± 7.4 cm to 35.9 ± 8.2 cm demonstrates that this study supports the findings of [51].

The study by [41], which included WBV exercises at 26 Hz and 4 mm amplitude added to the warm-up routine, found a 6% increase in peak force applied by sprinters at the block start, while no difference was found in 30 m sprint times. Another study [52] concluded that WBV training performed 3 days a week, in addition to traditional training at 40 Hz and 2.5 mm amplitude, had no effect on improving sprint performance. In another study [53], a statistically significant increase in vertical jump performance was found in basketball players after 4 weeks of WBV training, but no change was observed in 10 m sprint performance. Additionally, the study by [54] investigated the acute effect of WBV exercises lasting 30 seconds at 50 Hz and 3 mm amplitude on 15 m, 30 m, and 45 m sprint performances and concluded that this WBV exercise protocol did not have an acute effect on sprint development.

In the study by [25], it was determined that both plyometric exercises and exercises with WBV had a statistically significant positive effect on CMJ and agility time ($p < 0.001$). While CMJ and agility performance were higher in the plyometric group, speed performance was higher in the WBV group; however, these differences were not statistically significant between the two groups. Additionally, the study by [55] stated that all fencing performances increased significantly within 1 minute and 2 minutes after WBV with a frequency of 30 Hz and an amplitude of 2 mm. As seen in the recent literature reviewed, while there are many studies on the acute and chronic relationship between WBV and motoric characteristics, there is no study examining the acute effect of WBV combined with dynamic exercise on DL and NDL on sprint and jumping. It is thought that the present study makes a significant contribution to the literature.

Practical Applications

The acute effect on P and especially on P_{NDL} and HF_{NDL} during the 30 m sprint showed that WBV can be used as a short-term training method to improve P_{NDL} and HF_{NDL}. In studies to determine the acute and chronic effects of exercises with WBV on various performance parameters, focusing on the frequency and amplitude differences in certain protocols will provide more specific information about the effects of this training method.

Conclusions

In conclusion, dynamic movements such as repetitive lunges with WBV to DL and then to NDL highlighted the effect especially on sprinting, showing that WBV can also contribute to the training of different sports that require speed.

Conflict of interest

The authors have no conflicts of interest to declare.

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ORIGINAL ARTICLE

Hydration management in rugby: a comparative study on the forward and back positions of the Indonesian national team

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Abstract

Background and Study Aim: In the Indonesian national rugby team, there is a lack of awareness among back and forward players about the amount of fluids they lose while playing their respective positions. This is due to the different intensity and roles associated with each position. The aim of this research is to determine the difference in body fluid loss between players in the forward and back positions in the Indonesian national rugby team.

Material and Methods: The research method used in this study was an experimental method with a two-group pre-test and post-test design. The data collection process employed purposive sampling with the criterion of selecting 12 individuals from a population of 23 who were willing to participate. The data analysis technique used was the independent t-test.

Results: The research results concluded that there was a significant difference in body weight between the initial and final tests for players in the forward position. The t-count of 7.661 exceeded the t-table value of 2.571. Similarly, for players in the back position, there was a significant difference in body weight before and after the match. The t-count of 4.805 exceeded the t-table value of 2.571. Furthermore, when comparing fluid loss between forwards and backs, there was a significant difference. The t-count of 2.443 was greater than the t-table value of 2.222. This demonstrates the difference in fluid loss after competing with the Indonesian national rugby team.

Conclusions: The weight of both forward and back players decreased after competing. There are differences in body fluid loss between the two positions, with forwards losing more fluid than backs. This study provides empirical evidence that the position played on the field influences the amount of body fluid lost during the game. This insight is important for developing customized hydration strategies that consider the specific physical demands of each playing position.

Keywords: body fluid, rugby, forwards, backs, hydration management

Introduction

The human body consists mostly of fluids that are distributed inside cells (intracellular) and outside body cells (extracellular). Maintaining the balance of these fluids is crucial, as any imbalance can lead to weakness, lack of focus, and difficulty concentrating.

In adult men, fluids make up 60% of their body composition [1]. These fluids function as regulators of body temperature, blood circulation, and as lubricants and protectors for movement in muscle joints [2]. The fluids in the body are always changing in concentration, quantity, and type [3]. Water is obtained in three ways: drinking, eating, and the oxidation of food in the body [4]. The greatest body fluid loss through the skin occurs in the form of sweat during strenuous activities, reaching up to 5,000 ml/day. If there is an imbalance of fluids in the body, it can lead to weakness, lack of focus, and difficulty concentrating [5, 6].

Dehydration is related to an imbalance between body fluids that enter and exit the body. In the world of sports, dehydration often occurs due to uncontrolled fluid intake, regardless of actual fluid needs. In this case, body fluids can be lost through urine, sweat, and breathing [7]. The impact of dehydration on the body includes reduced cognitive ability or difficulty concentrating, and decreased stamina and work productivity [8, 9]. Dehydration, accompanied by reduced carbohydrate stores, is one of the main factors causing decreased body performance during exercise [10]. Overall, dehydration negatively impacts multiple physiological functions, leading to impaired performance [11].

When participating in sports activities, body fluids are lost with each movement, depending on the intensity and volume performed. In general,

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studies assessing physiological responses and performance typically use dehydration levels of 2% body mass or greater [12, 13]. This ensures sufficient fluid loss to produce measurable changes, as such levels of dehydration are common among athletes. Rugby union players should try to prevent severe dehydration (insufficient fluid intake relative to fluid loss) or hyperhydration (excessive fluid intake relative to fluid loss) during matches and training [14, 15]. When exercising, most of the water lost from the body is through sweat. To avoid a significant decrease in performance, this water must be replaced, both during matches and training [16, 17].

Rugby is starting to be widely played in Indonesia. This is evidenced by the emergence of many rugby tournaments at the national, regional, and inter-school levels [18, 19]. In the sport of rugby, there are two official formats, Rugby 7 and Rugby 15, each with different intensity and volume in each match [20, 21]. The times and number of players vary; specifically, Rugby 15 features 15 players and 8 reserves. In Rugby 15, there are various positions, namely forwards and backs [22]. Different physiques will naturally orient players to certain positions over others [23, 24, 25]. During a 70-minute match, forwards perform approximately three times as much high-intensity work (11.2 ± 0.9 min) as backs (3.6 ± 0.5 min) [26, 27].

In the world of sports, especially rugby, hydration management is a critical aspect that influences athlete performance [28, 29]. Fluid balance in the body is not only important for maintaining peak performance but also for preventing injury and ensuring effective recovery [30, 31]. In the context of the Indonesian national rugby team, hydration management often receives less attention, particularly regarding the specific needs of players in the forward and back positions. Forwards, who are often involved in scrums and rucks, may have different hydration demands compared to backs, who engage in more running and fast movements [32].

The role of coaches in educating players in the back and forward positions about fluid loss is still very minimal. This is directly related to the consequences of dehydration or inappropriate hydration patterns in athletes [11, 33]. If this situation continues, athletes may experience impaired body function, resulting in suboptimal performance. The effectiveness of fluid loss management for forwards and backs is not yet well understood, which hinders the Indonesian Rugby 15 National Team coaches from effectively advising athletes on proper fluid consumption. Athletes often do not pay sufficient attention to their fluid loss during play or competition. They typically consume water only when they feel thirsty, focusing solely on quenching their thirst rather than maintaining proper hydration levels. This approach does not ensure that the fluid intake matches the fluid loss during competition.

Although several studies have investigated hydration management, most previous research tends to generalize the hydration needs of athletes without considering differences in physical demands between positions in rugby. For example, the research by Roberts et al. [34] explains the nutrition protocol for rugby athletes in general. Another study by Scanlon and Norton [35] examined nutritional and body fluid requirements based on age.

However, there is still a lack of specific research focusing on the distinct hydration needs of players in different positions within the same rugby team. This gap highlights the need for targeted studies to develop tailored hydration strategies that consider the unique physical demands of each position.

The aim of this research is to compare the hydration needs of forward and back players on the Indonesian national rugby team.

Materials and Methods

Participants

This research was carried out during the Asia Rugby Championship Division 3 East-South match held at the Rugby Field Complex of Bung Karno Senayan, Jakarta. The population of this research consisted of all Indonesian Rugby 15 athletes. A purposive sampling method was used, with the following sample characteristics:

1) participants took a weight test at the beginning of the research;
2) participants played during matches;
3) participants played until the last round;
4) participants took a weight test after competing.

Out of 23 athletes, 11 could not be included in the study due to not meeting the criteria, while 12 athletes met the criteria and were included in the study.

Research Design

This research was designed as a comparative observational study, using a quantitative approach to collect data regarding athletes' weights before and after competition. The "Two Groups Pretest-Posttest" method was used to determine the lost body fluid in the positions of forwards and backs in the Indonesian national Rugby 15 team. This design allows the research to accurately measure and compare the level of dehydration experienced by these two positions before and after the match.

Data Collection

Data collection began by explaining in detail the purpose of the research, the procedures to be followed, the possible benefits, potential risks, and the participants' right to withdraw from the research at any time without consequences. The identities of

respondents and data obtained from the research were kept confidential to meet ethical standards. Data were obtained by weighing the athletes before and after competing to determine body fluid loss in the forward and back positions. The data collection process was as follows:

1) Athletes took off their clothes to measure their weight, wearing only shorts and sarongs;
2) Athletes relaxed and stood on the scale;
3) Each athlete's body weight was measured and the researcher recorded the results;
4) Athletes competed in the match;
5) After cooling down, the athletes prepared to have their weight measured again;
6) Athletes relaxed and stood on the scale;
7) Each athlete's weight was measured again and the researcher recorded the results.

Statistical Analysis

After the initial and final test data were collected, the data were processed and analyzed using descriptive analysis and independent t-test techniques. Before carrying out the analysis, the data collected from the initial and final tests were prepared, which included data cleaning such as checking and correcting data entry errors, identifying and resolving missing values, and ensuring that all data were entered correctly and consistently. The first step in the analysis was to apply descriptive analysis, which involved calculating basic statistics to gain a general understanding of the data. These statistics included mean, standard deviation, and minimum and maximum values. After conducting the descriptive analysis, the next step was to use the independent t-test to compare the averages of two independent groups, namely players in the forward and back positions. This t-test was used to determine whether there was a statistically significant difference in body fluid loss between the two positions. Data analysis was carried out with the help of SPSS 24.0.

Results

Description of Fluid Loss in Forward Position

Data on the results of the research regarding body fluid loss in the forward position in the Indonesian national Rugby 15 team can be seen in Table 1. Based on Table 1, there are initial weight data results and final weight data for the forward position. The initial weight test data for players in the forward position (X1) showed the heaviest body weight being 124.3 kg, the lowest body weight being 89.1 kg, with an average of 101.283 kg, a standard deviation (Sx1) of 13.860, and a standard error mean (SEmx1) of 6.215. The final weight test data for players in the forward position (X2) showed the heaviest body weight being 122.8 kg, the lowest weight being 87.0 kg, with an average of 99.0 kg, a standard deviation (Sx2) of 13.880, and a standard error mean (SEmx2) of 6.224. In the initial and final tests, there was a decrease in body fluids in players in the forward position, with the highest value being a decrease of 3500 ml, the lowest value being 1500 ml, an average of 2283.33 ml, a standard deviation (SDx) of 664.580, and a mean standard error (SEMX) of 298.017.

Table 1. Data Description of Fluid Loss in Forward Position

Variable	Initial Weight	Final Weight	Losing Fluid (ml)
Highest Value	124.3	122.8	3500
Lowest Value	89.1	87.0	1500
Average	101.283	99.0	2283.333
Standard Deviation	13.860	13.880	664.580
Error Standard	6.215	6.224	298.017

The detailed results of the athletes' weighing before and after competing in the forward position can be seen in Table 2. The heaviest initial body weight was recorded by "A" at 124.3 kg, and the lowest weight was recorded by "E" at 89.1 kg. Meanwhile, the heaviest final weight was also recorded by "A" at 122.8 kg, and the lowest final weight was recorded by "E" at 87.0 kg. Based on different tests using SPSS, a calculated t-value of 7.661 was obtained. The results were compared with a t-table value at degrees of freedom (df) = n-1 = 6-1 = 5 with a confidence level (α) = 0.05, yielding a critical t-table value of 2.571. Thus, the t-count value was greater than the t-table value (t-count 7.661 > t-table 2.571). The results of the research indicate that for players in the forward position, there is a significant difference in body weight between before and after the match. This difference is attributed to the numerous activities carried out by the forwards during competition.

Table 2. Weight of Players in the Forward Position

No.	Name	Gender	Weight (kg)	
			Initial	Final
1	A	Male	124.3	122.8
2	B	Male	112.3	108.8
3	C	Male	94.1	91.8
4	D	Male	94.9	92.6
5	E	Male	89.1	87.0
6	F	Male	93.0	91.0

Description of Fluid Loss in Backs Position

Data on body fluid loss in the backs position in the Indonesian national Rugby 15 team can be seen in Table 3. Based on Table 3, there are initial and final weight data for players in the backs position. The initial weight test data for players in the backs position (Y1) showed the heaviest body weight being 90.5 kg and the lowest being 70.0 kg, with an average

of 80.6 kg, a standard deviation (Sy1) of 7.976, and a standard error of the mean (SEmy1) of 3.570. The final weight test data for players in the backs position (Y2) showed the heaviest body weight being 87.9 kg and the lowest being 68.9 kg, with an average of 79.3 kg, a standard deviation (Sy2) of 7.272, and a standard error of the mean (SEmy2) of 3.260. In the initial and final examinations, there was a decrease in body fluids in players in the backs position. The highest value for the decrease in body fluids was 2300 ml, and the lowest was 700 ml, with an average of 1300 ml, a standard deviation of 603.324, and a mean standard error (SEMY) of 270.548.

Table 3. Data Description of Fluid Loss in Backs Position

Variable	Initial Weight	Final Weight	Losing Fluid (ml)
Highest Value	90.5	87.9	2300
Lowest Value	70.0	68.9	700
Average	80.6	79.3	1300
Standard Deviation	7.976	7.272	603.324
Error Standard	3.570	3.260	270.548

In detail, the results of athletes' weighing before and after competing for players in the backs position can be seen in Table 4. The heaviest initial body weight was recorded by "G" at 90.5 kg, and the lowest weight was recorded by "L" at 70.0 kg. Meanwhile, the heaviest final weight was recorded by "G" at 89.7 kg, and the lowest final weight was recorded by "L" at 68.9 kg. Based on different tests using SPSS, a calculated t-value of 4.805 was obtained. The results were compared with a t-table value at degrees of freedom (df) = n-1 = 6-1 = 5 with a confidence level (α) = 0.05, yielding a critical t-table value of 2.571. Thus, the t-count value was greater than the t-table value (t-count 4.805 > t-table 2.571). The results of the research indicate that for players in the backs position, there is a significant difference in body weight between before and after the match. This difference is attributed to the observation that during the game, the backs performed less work or fewer activities.

Table 4. Weight of Players in the Backs Position

No.	Name	Gender	Weight (kg)	
			Initial	Final
1	G	Male	90.5	89.7
2	H	Male	89.1	87.9
3	I	Male	80.9	78.6
4	J	Male	76.7	75.0
5	K	Male	76.1	75.4
6	L	Male	70.0	68.9

Comparison of the Initial and Final Test on the Forward and Backs Position

Based on the results of the final test of body fluid loss in rugby players in forward and back positions, a different standard error of the mean (SEmxmy) of 402.499 was obtained. Using SPSS for the different test, a t-count of 2.443 was calculated. This t-count value was compared with the t-table value at a degree of freedom (df) of (n1 + n2) - 2 = (6 + 6) - 2 = 10 and a confidence level (α) of 0.05, yielding a critical t-table value of 2.228. Since the t-count of 2.443 is greater than the t-table value of 2.228 (t-count 2.443 > t-table 2.228), the results indicate a significant difference in body fluid loss between players in the forward position and those in the backs position in the Indonesian national Rugby 15 team. This can be understood because the more activity or work done, the more body fluids are excreted, meaning forward players exert more effort than players in the back position.

Discussion

The results of this study show that there is a significant difference in body fluid loss between players in the forward and back positions in the Indonesian national Rugby 15 team, with forward players experiencing greater fluid loss compared to back players. These findings are consistent with previous studies indicating that rugby players who engage in more intense physical activity and more frequent physical contact tend to lose more body fluid during the game [36, 37]. This highlights the importance of effective hydration management in rugby, especially for players in forward positions who are at greater risk of dehydration.

Forward players are usually involved in many activities such as scrums and rucks, which require great physical effort and result in increased heat production and fluid loss through sweat [38]. These activities lead to significant heat production and excessive sweating, causing substantial loss of body fluids [23, 24]. In contrast, backs engage in more sprinting and long-distance running, which also requires high effort but involves less duration and frequency of contact compared to forwards, resulting in lower fluid losses [39]. This study confirmed these findings, with the average player in the forward position losing 2283.333 ml of fluid, while players in the back position lost an average of 1300 ml.

When players compete, especially for long durations or at high intensity, the body produces sweat as a cooling mechanism. This process causes fluid loss from the body, which directly affects body weight. This research shows that weight loss occurs before and after the match in both forward and back players. Significant fluid loss without adequate replacement can lead to dehydration, which has been shown to affect physical and cognitive performance [40, 41]. Dehydration of 2% of body weight can reduce aerobic capacity, strength, and stamina,

which are crucial in high-intensity sports such as rugby [12, 13]. In addition to reduced physical performance, dehydration can also lead to decreased ability to concentrate and maintain alertness, which are important factors in making quick and accurate decisions on the field [11, 42]. This means that players who are not sufficiently hydrated may have difficulty following game strategy and responding effectively to match situations. Furthermore, dehydration can affect the body's thermal homeostasis, increasing core temperature and potentially leading to adverse health effects such as heat exhaustion or even heat stroke in extreme conditions [43]. The cardiovascular system is also affected, with dehydration resulting in increased blood viscosity, which can raise the risk of thrombosis and overwork the heart as it strives to maintain adequate blood flow to muscles and other vital organs [44].

From a hydration management perspective, these results underscore the importance of differentiated hydration strategies based on players' positions during the match [41, 45]. Coaches and medical teams should design more specific and targeted hydration protocols for forward players to optimize performance and reduce their higher risk of dehydration. Efforts to increase awareness of the importance of proper and effective hydration should be intensified, especially among forward players who are prone to dehydration. It is also important to consider the health consequences of significant body fluid loss [46]. Dehydration can cause a variety of health problems, including decreased physical and cognitive performance. In high-intensity sports such as rugby, where physical performance and endurance are critical, effective hydration management can be a determining factor in team success [47, 48].

Conclusions

This research reveals that there is a significant difference in fluid loss between forward and back players on the Indonesian national rugby team, with forward players losing more fluid than back players. Weight loss measured after competition indicates a reduction in body mass that can be directly attributed to dehydration occurring during intense physical activity. These findings have important practical implications for players, coaches, and medical staff of rugby teams. Understanding the differences in fluid loss between positions helps in developing more targeted hydration strategies. Coaches can use this information to design more effective training and match preparation programs, specifically considering hydration needs based on the intensity and nature of each position's physical tasks. Thus, implementing a more dynamic and customized hydration strategy will support players' optimal performance and reduce the risk of dehydration-related disorders.

This study makes an important contribution to the sports literature by identifying and documenting specific differences in fluid loss between player positions in rugby. However, this study has several limitations, including a limited sample size and a focus on only one national team. Additionally, this study did not directly measure electrolyte levels or other physiological parameters that may be affected by dehydration, which could provide a more complete picture of the physiological effects of fluid loss. Future research could target larger sample sizes and diverse teams to validate these findings and expand their generalizability. Additionally, it would be beneficial to include measurements of electrolytes and other physiological variables to better understand the impact of dehydration on rugby players. Future researchers could also consider evaluating the effectiveness of different hydration strategies to determine which are most effective for players in various positions.

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Conflict of Interest

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ORIGINAL ARTICLE

Effect of vitamin D on body mass index in football athletes

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Abstract

Background and Study Aim: Vitamin D deficiency is a critical issue for athletes, and the major cause of Vitamin D deficiency is the involvement of athletes in indoor sports activities. Indoor training of athletes has similar risk factors for vitamin D deficiency as compared to the rest of the population. Therefore, this study aimed to examine the influence of Vitamin D on BMI among football athletes in Pakistan.

Material and Methods: Twelve football athletes (n=6 Experimental Group, n=6 Control Group) from Mian Kalay were recruited through a convenient sample with the average age of the participants being 19.08 ± 2.35 years. Weight, height, and body mass index were measured using a standard stadiometer (ZT-120, China) and analyzed using SPSS version 26. The Experimental Group was kept in games with sunlight exposure for a period of 120 days while the Control Group was restricted. Blood samples were collected by an Agha Khan Lab expert using a 3cc syringe, then transferred into a 3cc gel tube, and 1ml of serum was obtained after centrifugation from all participants.

Results: The Experimental Group showed significant increases in Vitamin D levels (17.58 vs 43.36, p-value 0.003) and decreases in weight (p=0.001) and BMI (24.00 vs 22.32, p-value <0.001). Meanwhile, the Control Group experienced decreases in Vitamin D levels (20.85 vs 10.86, p-value 0.036) and increases in weight (p<0.001) and BMI (21.11 vs 21.60, p-value 0.023) due to restriction from sunlight.

Conclusions: Training in sunlight significantly increased the Vitamin D levels of athletes and decreased their weight and BMI. Moreover, indoor sports activities significantly decreased Vitamin D levels and increased the weight and BMI levels of athletes.

Keywords: BMI, flood affected, athletes, sunlight, weight, sports activities, obesity

Introduction

Vitamins are a separate group of dietary substances required in small quantities for healthy growth and body metabolism [1]. Vitamins are divided into water-soluble and lipid-soluble categories according to their solubility. Water-soluble vitamins include the B complex and vitamin C, while the lipid-soluble vitamins are A, D, E, and K [2]. They perform multiple complex functions in our body, such as acting as antioxidants, influencing hormones, coenzymes, signaling, regulating cells, and aiding in the growth and differentiation of tissues [3].

Vitamin D is one of the fat-soluble vitamins known for its role in bone mineral metabolism [4]. It exists in two forms: vitamin D2 (calciferol), synthesized by plants, and vitamin D3 (cholecalciferol), which is produced under the skin's subcutaneous adipose tissues through the effects of sunlight on 7-dehydrocholesterol [5]. During activation, 7-dehydrocholesterol undergoes photochemical changes and is transported by vitamin D binding protein (DBP) to the liver [6]. The DBP facilitates several hydroxylation phases. Initially, it transports 7-dehydrocholesterol to the liver where it is converted to 25-hydroxyvitamin D3 (25, OH D3). In the second phase, it is transported to the kidney where it is synthesized into the active form, 1,25-dihydroxyvitamin D3 (1, 25(OH)2 D3), by 1-alpha hydroxylase enzymes. Furthermore, the conversion of 25(OH) D3 to its active form, 1, 25(OH)2 D3, significantly involves the Vitamin D receptor (VDR) [7]. The active form of vitamin D3 plays a crucial role in maintaining mineral homeostasis (calcium and phosphorus) in the body [8]. Additionally, vitamin D levels in the human body are assessed through blood serum measurements. Athletes are considered vitamin D deficient if their levels are below 50 nmol/L and sufficient if levels are above 50 to 75 nmol/L [9].

Sunlight is the most abundant source of vitamin D. However, research studies have identified other dietary sources that naturally contain 25-hydroxyvitamin D3. These sources include pulses, egg yolks, various types of fish (such as

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fatty fish and salmon), and fortified foods like milk, cereals, oranges, and juices [10]. Vitamin D levels can vary in human bodies due to different geographical conditions, such as season, altitude, longitude, and also based on age and gender differences among ethnic groups [11].

Anthropometry, derived from Greek terminology, is used to measure the structure and characteristics of the human body. It is particularly applied to assess the body composition (shape and size) of athletes [12]. Anthropometry provides sports administrators with valuable information about each sport's physical fitness and athletic performance [13]. Its current importance in sports offers significant contributions to the evaluation of physical fitness and performance, crucial for athlete selection [12]. These characteristics have beneficial effects on athletes' competition outcomes [13]. Various anthropometric markers, including weight, height, body mass index (BMI), waist-to-hip ratio (WHR), and waist circumference (WC), have been used to determine the risk factors for cardiovascular diseases (CVD) and diabetes in athletes [14].

A research study reported that BMI, calculated as body weight in kilograms divided by height in square meters, is used to assess body fat, overweight, or severe obesity, which are linked to other risk factors for diabetes and cardiovascular diseases [15]. Due to its simplicity, BMI is the most well-known method for measuring body composition [16]. Additionally, the research indicated that BMI levels are generally higher in boys than in girls within the same age group [15]. The World Health Organization categorizes BMI on an individual basis.

Increasing BMI levels are associated with more chronic health issues, including cardiovascular diseases and diabetes, which are major causes of death worldwide [17]. BMI is not only indicative of fat distribution in the body but also highlights chronic diseases associated with waist circumference and waist-to-hip ratio. Furthermore, BMI provides more comprehensive data for assessing the risk of CVD and type 2 diabetes compared to other tools [16].

The ratio of vitamin D serum concentration is lower in obese individuals compared to those of normal weight. Vitamin D status is inversely correlated with body weight, fat mass, and BMI. Similar results have been observed in children and adult populations in Europe, New Zealand, Australia, Saudi Arabia, and the USA [18]. In obese individuals, vitamin D concentration is 20% lower than in normal-weight individuals. A clinical trial involving 383 overweight and obese women was conducted to study weight loss over a period of 24 months and examine 25-hydroxyvitamin D (25(OH) D) status. The study found that vitamin D levels increased by 2.7 ng/ml and participants lost 5-10% of their baseline weight. An increase of 5.0 ng/ml in vitamin D levels was associated with a reduction of more than 10% of baseline weight [18]. Additionally, research has provided substantial evidence that higher vitamin D concentrations lead to weight reduction. This characteristic of 25(OH)D has been increasingly recognized for its protective benefits against various chronic diseases. The prevalence of vitamin D deficiency in obese individuals ranges from 40-80% [20, 21]. It has been observed that a low serum concentration of vitamin D is a distinct feature associated with obesity. From a genetic perspective, research has highlighted that high BMI and certain genes reduce vitamin D status in obese individuals, while the impact of low vitamin D levels and genes on obesity is less significant [22].

Despite the extensive research linking vitamin D deficiency with various health outcomes, there remains a gap in the specific analysis of its effects on body composition among athletes, particularly in diverse climates and geographical regions. Previous studies have often focused on general populations or non-athletic groups, and few have addressed the potential variations in vitamin D metabolism due to intense physical activity and outdoor exposure specific to athletes. Moreover, the influence of vitamin D on body mass index (BMI) has been inconsistently reported, highlighting a need for more targeted research in athletic populations. Therefore, this study aimed to examine the influence of Vitamin D on BMI among football athletes in Pakistan.

Materials and Methods

Participants

A total of 12 participants were included in the study, divided equally between the control group and the experimental group (n=6 each). The sample comprised only healthy male football players who were skilled in the sport. The participants were aged between 15 and 24 years. Inexperienced players, females, and individuals outside of the age range (<15 and >24 years) were excluded from the study. Participants refrained from smoking and using drugs during the study period. Informed consent was obtained from the parents or legal guardians of each participant. Informed consent was also obtained from the adult participants. The study protocol was reviewed and approved by the Ethical Review Board of Sarhad University of Science & Information Technology.

Research Design

Fieldwork procedures were conducted from October 2017 to February 2018. Blood samples, height, age, weight, and BMI were measured during both pre-test and post-test phases. Participants in the experimental group were recruited from a local football club in the Mian Kalay district of Lower Dir, a flood-affected area. For these participants, parameters such as height, age, weight, BMI, and

serial blood samples were measured during the pre-test. The sunlight exposure schedule was specifically arranged for the experimental group and lasted 120 days. Daily sunlight exposure was scheduled from 2:00 PM to 3:30 PM. Google weather forecast was utilized to exclude cloudy and rainy days. During the sunlight exposure, participants wore shirts and shorts.

Participants in the control group were students from GHSS (Government Higher Secondary School) Mian Kalay. Blood samples were taken as a pre-test. These participants were restricted from sunlight exposure for 120 days. All control group members used umbrellas and gloves for sunlight protection while engaged in school activities from 8:00 AM to 2:30 PM. After school hours, they attended Madrasa for religious studies and occasionally played games in the evening. The study adhered to well-known standards: Vitamin D classification (Table 1) and WHO BMI classification (Table 2).

Statistical Analysis

All data were statistically analyzed using SPSS version 20. The mean ± SD (standard deviation) was calculated for each group. Data from the experimental and control groups were assessed at both pre- and post-stages using paired sample t-tests. An independent sample t-test was employed to compare the two groups with each other at both pre- and post-test intervals. Data were tabulated and graphically represented appropriately. A p-value of $\leqslant 0.05$ was considered statistically significant.

Results

The demographic parameters of all participants are outlined in Table 3. After confirming the normality of the data, which is detailed in Table 3, participants who were inexperienced players, females, or outside the age range of 15 to 24 years were excluded. Data for both groups were thoroughly analyzed at both pre- and post-test intervals. A paired sample t-test was used to compare the levels of vitamin D, weight, and BMI, as detailed in Table 4.

The control group experienced a significant decline in vitamin D levels after four months of non-exposure and showed an increase in weight and BMI. Table 5 demonstrates a significant reduction in weight and BMI, detailing the mean, standard deviation, and probabilities due to a four-month sun

Table 1. Holick Classification of Vitamin D at Agha Khan Lab [23].

Reference Ranges	Quantity in (ng/mL)	Quantity in (nmol/L)
Vitamin D Deficiency	<20	<50
Vitamin D Insufficiency	21 - 29	52.5 - 72.5
Vitamin D Sufficiency	Or >30	>75
Vitamin D Intoxication	> 150	>375

Table 2. WHO Classification of Individuals BMI [24].

BMI Range	Weight Definition
Underweight	<18.5 kg/m^2
Normal	18.5-24.9 kg/m^2
Overweight	25-29.9 kg/m^2
Obese	30-39.9 kg/m^2
Severely Obese	⩾40

Table 3. Participants Demographics & Variables

Variables	Pre Values	Post Values
Number (n)	12 (n=6 Exp, n=6 Cont)	
Age (Yrs)	19.08 ± 2.35	
Height (m)	1.67 ± 0.07	1.68 ± 0.07
Weight (kg)	63.25 ± 13.16	63.08 ± 11.92
BMI	22.55 ± 4.55	22.4 ± 4.38
Vitamin D (ng/ml)	19.216 ± 5.52	27.11 ± 19.88

Table 4. Paired Sample t-Test Indicates Control Group Parameters. Both pre and post-tests have shown the mean, standard deviation, differences, and their p-values.

Variables	Pre Value (Mean ± SD)	Post Value (Mean ± SD)	Mean ± SD Difference	P-Value
Height (m)	1.62 ± 0.06	1.63 ± 0.06	0.01 ± 0.01	0.076
Weight (kg)	55.50 ± 9.20	57.50 ± 9.06	2.00 ± 0.31	<0.001
BMI	21.11 ± 3.21	21.60 ± 3.16	0.49 ± 0.36	0.023
Vitamin D (ng/ml)	20.85 ± 7.22	10.86 ± 6.53	-9.99 ± 8.59	0.036

Table 5. Paired Sample t-Test Indicates Experimental Group Parameters

Variables	Pre Value (Mean ± SD)	Post Value (Mean ± SD)	Mean ± SD Difference	P-Value
Height (m)	1.73 ± 0.05	1.73 ± 0.05	0.00 ± 0.00	-
Weight (kg)	71.00 ± 12.34	68.66 ± 12.48	-2.34 ± 0.40	<0.001
BMI	24.00 ± 5.50	23.2 ± 5.53	-0.80 ± 0.12	<0.001
Vitamin D (ng/ml)	17.58 ± 2.91	43.36 ± 13.92	25.78 ± 11.77	0.003

Table 6. Comparison of Demographic Parameters between Experimental and Control Groups through Independent Sample t-Test

Variables	Pre Test Control (Mean ± SD)	Pre Test Experimental (Mean ± SD)	P-Value	Post Test Control (Mean ± SD)	Post Test Experimental (Mean ± SD)	P-Value
Height (m)	1.62 ± 0.06	1.73 ± 0.05	0.025	1.63 ± 0.06	1.73 ± 0.05	0.029
Weight (kg)	55.50 ± 9.20	71.00 ± 12.34	<0.01	57.50 ± 9.06	68.66 ± 12.48	0.015
BMI	21.11 ± 3.21	24.00 ± 5.50	<0.01	21.60 ± 3.16	23.2 ± 5.53	0.037
Vitamin D (ng/ml)	20.85 ± 7.22	17.58 ± 2.91	0.062	10.86 ± 6.53	43.36 ± 13.92	<0.001

exposure trial. A directly proportional relationship was observed, with vitamin D levels increasing during the period of sunlight exposure.

The analyses were extended to include an independent sample t-test for the demographic parameters of weight, height, and BMI, as outlined in Table 6. Significant differences were found in these parameters at both pre and post stages. While vitamin D levels were independent at the pre-test stage, significant differences in vitamin D levels were observed at the post-test stage.

Discussion

Vitamin D deficiency is a widespread epidemic and a re-emerging issue that is associated with major global health problems. The primary causes of vitamin D deficiency are lifestyle-related, particularly the avoidance of sunlight. This inclination is not limited to the general public; it is also prevalent among professional athletes. As a result, the majority of people, including athletes, suffer from hypovitaminosis, functional disorders, and chronic injuries. Such functional disorders can lead to defective bone mineralization, as seen in conditions like rickets and osteomalacia. The misconception that avoiding sunlight is beneficial is one of the primary reasons athletes participate in indoor games, which can adversely affect their performance.

This study aimed to examine the influence of Vitamin D on BMI among football athletes in Pakistan. The findings indicate significant differences in Vitamin D levels, weight, and BMI between the experimental and control groups. Specifically, the experimental group, which was exposed to sunlight, showed an increase in Vitamin D levels and a decrease in weight and BMI after the 120-day trial period. Conversely, the control group, which avoided sunlight, exhibited a decline in Vitamin D levels and an increase in both weight and BMI. These results are outlined in Tables 4, 5, and 6, demonstrating the impact of sunlight exposure on Vitamin D levels and associated changes in body composition.

Further evidence underscores that vitamin D is essential for maintaining strong bones, reducing inflammation, and preventing stress fractures and impaired muscle function [25]. Studies in the US have highlighted that athletes' dietary intakes often do not meet their bodily needs. Moreover, it has been observed that vitamin D levels can vary significantly based on factors such as time of outdoor training (afternoon), geographic location, and skin color [26]. Additional research indicates that athletes with low

concentrations of vitamin D experience higher bone turnover than those with higher vitamin D levels [27]. Vitamin D is crucial not only for bone health but also for reducing the risk of stress fractures, muscle injuries, and enhancing overall physical performance [28]. A significant difference in vitamin D levels has been reported between indoor and outdoor athletes, across an age range of 10 to 30 years, demonstrating the positive effects of sunlight on vitamin D synthesis [29]. Sunlight exposure has been shown to positively influence multiple body functions, reducing pain and injuries, and improving athletic performance, including reaction time, speed, strength, and endurance [30].

Unlike previous studies that broadly associate vitamin D with general health benefits, our results pinpoint specific improvements in BMI and weight management in athletes exposed to optimal sunlight conditions. Additionally, our research underscores a more pronounced difference in vitamin D levels between indoor and outdoor athletes than typically reported, suggesting that even minimal but consistent sunlight exposure could be more beneficial than previously understood.

European researchers have found that sunlight exposure enhances the performance of athletes [10]. A similar outcome was observed in both our experimental and control groups, where all participants had a low mean level of vitamin D (19.216 ± 5.52) according to the Holick classification. It was noted that chronic vitamin D deficiency has serious effects on the performance, growth, and nourishment of players. Research also highlights seasonal variations in vitamin D levels, with female runners and gymnasts showing lower levels in winter (15 ng/ml) compared to summer (25 ng/ml) [31]. The widespread deficiency and seasonal variations are influenced by factors such as gender, age, and BMI. The prevalence of vitamin D deficiency is higher among women (ratio 1:3) and men (ratio 1:2) with a BMI $\geqslant 40$ [21]. Additionally, studies have focused on weight loss in obese individuals through calorie reduction and increased exercise [32], noting that vitamin D concentration is positively associated with obesity. Hypovitaminosis D affects cholesterol metabolism and tends to increase weight levels [33].

Our study aligns with European findings that sunlight enhances athletic performance, as both our experimental and control groups exhibited similar patterns in vitamin D levels. However, unlike the seasonal variation observed in female athletes from other studies, where vitamin D levels fluctuated between winter and summer, our participants consistently displayed low vitamin D levels regardless of season. Additionally, our findings suggest a broader demographic impact, with significant deficiencies noted across different genders and age groups, and not just confined to specific categories such as female runners and gymnasts. This highlights a more generalized vitamin D deficiency within our study population that contrasts with the specific seasonal variations reported elsewhere.

In various sports events, physical performance and techniques improve with sufficient vitamin D levels [10]. Research indicates that genetic factors influence vitamin D levels alongside body weight, waist circumference, and BMI [34]. Consistently, physical performance increased in the experimental group and decreased in the control group, suggesting that lack of sun exposure and inactivity during the four-month trial significantly impacted the control group's results. Most participant parameters are associated with the developmental stage, significantly affecting weight gain, which could disrupt lipid metabolism in athletes. Hypovitaminosis has been identified as a key factor in obesity, affecting waist circumference and BMI parameters. A study involving 276 premenopausal healthy females measured multiple demographic parameters, including waist circumference (WC), waist-to-hip ratio (WHR), obesity, abdominal obesity, and BMI. The results indicated that WC, WHR, BMI, obesity, and abdominal obesity ratios were lower in the vitamin D sufficient group compared to the deficient group [35]. This research underscores the impact of vitamin D on anthropometric measurements such as weight, height, and BMI, establishing that vitamin D levels are inversely proportional to weight and BMI.

Our findings corroborate existing research that demonstrates a positive correlation between sufficient vitamin D levels and improved physical performance and body composition metrics like weight and BMI. Specifically, our study revealed that participants with higher vitamin D levels (experimental group) experienced decreases in weight and BMI, contrasting with the control group, which had lower vitamin D levels and exhibited weight and BMI increases. This pattern aligns with other studies indicating that vitamin D sufficiency is associated with lower waist circumference, waist-to-hip ratio, and overall obesity levels. Our results underscore the significant impact of vitamin D on physical health and support broader findings that link adequate vitamin D levels with healthier body measurements and better performance outcomes.

Our study reinforces the critical role of vitamin D in enhancing physical performance and optimizing body composition among athletes. The findings highlight the positive effects of sunlight exposure on vitamin D levels, which in turn significantly impacts weight and BMI. These results not only corroborate previous studies but also extend our understanding by demonstrating the specific benefits of vitamin D for athletes, particularly in settings with optimal sunlight exposure. Future research should explore the mechanisms behind vitamin D's influence on

metabolic functions and athletic performance, and investigate the potential for targeted interventions that could help athletes maintain adequate vitamin D levels throughout varying seasons and training conditions.

Conclusions

Our research contributes to the existing knowledge regarding the effects of sunlight on increasing vitamin D levels in athletes. These insights are particularly valuable for sports scientists, coaches, and athletic trainers who are aiming to optimize athlete health and performance through nutritional and environmental strategies. Understanding the significant role of vitamin D can aid in developing targeted interventions that enhance athlete well-being and reduce the risk of vitamin-related deficiencies.

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Conflicts of interest

The authors declare no conflict of interest.

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