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The Effect of Blood Flow Restriction Training in Taekwondo Athletes

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ABSTRACT

Bo J, Anek A, Mitranun W. The Effect of Blood Flow Restriction Training in Taekwondo Athletes. The purpose of this study was to enhance the performance of high-level athletes through blood flow restriction (BFR) training. Twenty elite Taekwondo athletes from China were randomly assigned to either the Experimental Group or the Control Group. The Experimental Group underwent 8 weeks of BFR training at 50% arterial occlusion pressure (AOP), with 3 sessions per week, while the Control Group followed traditional high-intensity resistance training at 70% of one-repetition maximum (1RM). The Experimental Group showed significant improvements in body composition, including reduced body fat (P = 0.035, Cohen's d = -0.53) and increased muscle mass (P = 0.004, Cohen's d = 0.51). In contrast, the Control Group exhibited only a modest weight gain (P = 0.034). Additionally, the Experimental Group demonstrated substantial gains in thigh circumference (P < 0.001, Cohen's d = 0.771) and hip circumference (P = 0.034), along with enhanced lower limb explosive power. These findings suggest that BFR training is a more effective method than traditional resistance training for improving body composition, increasing muscle strength, and boosting lower limb explosive power in high-level athletes. In conclusion, BFR may be an important approach for athletes to optimize their performance.

Key Words: Arterial Occlusion Pressure, Counter Movement Jump, Explosive Power, Resistance Training

INTRODUCTION

Taekwondo, as a combat sport primarily focused on leg techniques, places exceptionally high demands on lower limb strength and explosive power. These attributes are among the key factors that enable taekwondo athletes to gain a competitive edge in matches (1). Through systematic and effective training methods, athletes can enhance their lower limb strength and explosive power, thereby improving their performance and competitiveness. Lower limb strength encompasses the anterior and posterior thigh muscles, and the gluteal muscles, all of which are critical for generating and controlling movements such as kicks, thrusts, and stomps. Improving lower limb strength allows athletes to execute more powerful and aggressive kicks while also enhancing stability and balance (2).

Explosive power, on the other hand, refers to the ability to exert force rapidly in a short period, directly influencing the speed and effectiveness of attacks. Enhancing explosive power equips athletes with sudden and impactful strikes, making it more challenging for opponents to defend and enable better responses to their attacks. To improve and develop lower limb strength and explosive power in taekwondo, coaches should emphasize the use of systematic and scientific training methods, including foundational strength training, kicking drills, explosive power exercises, and balance training. Additionally, attention should be given to proper nutrition and adequate rest to support recovery and growth (6).

With advances in science and technology, Blood Flow Restriction Training (BFRT) has emerged as an innovative training method that has gradually gained attention among taekwondo athletes and coaches (6). This technique involves applying moderate external pressure around muscles to restrict venous blood flow, which enhances the training effects. In the field of competitive sports, BFRT has become a common method for strength training and rehabilitation across various levels of athletes.

The previous study investigated the effects of blood flow restriction (BFR) combined with low-intensity resistance training on lower-limb muscle strength and mass in post-middle-aged adults. The results showed that BFR training led to greater muscle strength gains compared to normal activity and lower-limb muscle strength, and produced muscle strength gains comparable to those achieved with high-intensity resistance training (2). However, research on BFRT in elite taekwondo athletes remains relatively limited, particularly regarding its effectiveness and implementation strategies (4,8-10,12). Therefore, to promote and expand the application of BFRT in taekwondo teams, it is imperative to conduct further research on its principles and methodologies. This will help standardize BFRT practices, optimize training results, and enable athletes to achieve outstanding performance in competition.

METHODS

This study involved athletes from the elite Taekwondo Team at the School of Physical Education, Henan Normal University, China. Two high-level Taekwondo athletes, aged 18 to 20 years, were selected as subjects for the intervention and observation of blood flow restriction training (BFRT). The total sample included 6 national Taekwondo athletes, 6 Level I national Taekwondo athletes, and 8 Level II national Taekwondo athletes.

Before the experiment, all the participants voluntarily agreed to take part and provided informed consent after being fully briefed on the study’s procedures and potential risks. A preliminary health screening was conducted to confirm their mental and physical well-being to ensure that none of the participants had undergone lower limb surgery or had any medical conditions that could interfere with the study. Additionally, the athletes were instructed to avoid consuming caffeine and alcohol throughout the training period. Ethical approval for the study was granted by the Ethics Committee of the Physical Education College at Henan Normal University (Approval Number: HNSD-2024BS-0702).

Experimental Design
The participants were randomly assigned to 1 of 2 Groups: The Blood Flow Restriction Training (BFRT) Group or the Traditional Resistance Training (TRT) Group.

BFRT Group
Athletes in the BFRT Group trained using a KAATSU Master compression device (Japan) while performing low-intensity resistance exercises targeting the lower limbs. Their training program included squats, deadlifts, weighted lunges, and resistance running that aligned with the Taekwondo team's regular training plan. Before each session, a warm-up was conducted with compression applied. A 5 cm-wide compression belt was used, with an initial application pressure of 40 mmHg. During training, pressure was set at 50% of the individual's maximum arterial occlusion pressure (AOP), which was determined using reference values from Loenneke et al. (5). Each session consisted of 4 sets per exercise: The first set included 30 repetitions. The remaining 3 sets consisted of 15 repetitions each. Rest intervals between the sets were 60 seconds, with compression maintained throughout the entire session. Training was conducted 3 times per week for 8 weeks.

TRT Group (Control Group)
Athletes in the Control Group followed a traditional high-intensity resistance training (TRT) program at 70% of their one-repetition maximum (1RM). Their sessions were structured similarly to the BFRT Group. Each session included 4 sets per exercise. Repetitions per set ranged from 8 to 12. Rest intervals between sets were 3 minutes. The total training duration and frequency per week were identical to those in the BFRT Group. The same intervention-specific exercises were performed: squats, deadlifts, weighted lunges, and resistance running. Aside from the intervention-specific differences, both Groups followed the same overall training regimen. To minimize confounding variables, all the participants followed standardized dietary guidelines, rest schedules, testing procedures, and measurement protocols throughout the study.

Statistical Analyses

A repeated measures analysis of variance (ANOVA) with a 2 (Group: Pressurization Group vs. Control Group) × 3 (Time: pretest, midtest, posttest) design was used to assess the effects of the intervention. To control for potential confounding variables (baseline values, sex, BMI, and age), an analysis of covariance (ANCOVA) was performed. Group differences in outcome measures were further examined using the Bonferroni method for multiple comparisons. Effect sizes were calculated to quantify the practical significance of the findings, reported as partial eta squared (ηp^2) and Cohen's d, with thresholds defined as small (0.01/0.20), medium (0.06/0.50), and large (0.14/0.80) effects, based on Batista et al. (2013) and Richardson (2011). The significance level was set at $P < 0.05$.

RESULTS

We evaluated 20 elite taekwondo athletes aged 18 to 20 years. Table 1 shows that the BFRT Group experienced significant improvements in body fat, lean body mass, skeletal muscle mass, and body fat percentage (P < 0.05); whereas, the TRT Group showed a significant increase only in body weight (P < 0.05).

Table 1. Body Composition Data.

Indicator (unit)	Group	Pre	Post
Weight (kg)	BFRT	75.24 ± 8.96	76.24 ± 8.99
	TRT	74.98 ± 9.25	76.99 ± 8.98*
Body Fat (kg)	BFRT	9.58 ± 2.25	8.45 ± 1.99*
	TRT	9.65 ± 2.98	8.99 ± 2.20
Muscle Mass (kg)	BFRT	65.14 ± 7.56	69.25 ± 8.56*
	TRT	65.29 ± 8.12	67.25 ± 7.99
Skeletal Muscle Mass (kg)	BFRT	46.68 ± 5.04	47.97 ± 4.27*
	TRT	46.59 ± 5.55	47.05 ± 5.02
Body Fat (%)	BFRT	15.25 ± 4.68	13.51 ± 3.99*
	TRT	15.77 ± 4.98	14.01 ± 4.01

Use the "±" symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **BFRT** = Blood Flow Restriction Training, **TRT** = Traditional High-Intensity Resistance Training, *Different from pretest, significant at the .05 level.

Table 2 indicates that both Groups had a significant increase in hip circumference. However, an increase in left thigh circumference was observed only in the BFRT Group (P < 0.05).

Table 2. Body Circumference Data.

Indicator (unit)	Group	Pre	Post
Chest Circumference （cm）	BFRT	96.27 ± 8.54	97.06 ± 8.15
	TRT	97.11 ± 4.45	97.79 ± 5.21
Hip Circumference (cm）	BFRT	101.63 ± 4.98	103.19 ± 5.47*
	TRT	103.24 ± 5.51	104.94 ± 3.86*
Left Thigh Circumference (cm)	BFRT	61.41 ± 4.23	64.99 ± 4.10*
	TRT	62.76 ± 3.00	64.30 ± 3.34
Right Thigh Circumference (cm)	BFRT	61.90 ± 3.79	63.84 ± 3.95
	TRT	63.04 ± 2.47	64.51 ± 2.61
Left Calf Circumference (cm)	BFRT	40.31 ± 3.14	40.13 ± 2.88
	TRT	40.61 ± 1.48	40.34 ± 1.77
Right Calf Circumference (cm)	BFRT	40.46 ± 2.76	40.16 ± 3.08
	TRT	40.73 ± 1.79	40.51 ± 2.00

Use the "±" symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **BFRT** = Blood Flow Restriction Training, **TRT** = Traditional High-Intensity Resistance Training, *Different from pretest, significant at the .05 level. #Indicates a difference in comparison between Groups (P<0.05); ###Indicates a highly significant difference between Groups (P < 0.001).

Table 3 reveals that the BFRT Group achieved significantly greater improvements in trunk flexion, trunk extension, left trunk lateral flexion, right trunk lateral flexion, rotation to the left, and rotation to the right (P < 0.05). The TRT Group, on the other hand, showed significant improvements in trunk flexion, trunk extension, right trunk lateral flexion, and rotation to the left (P < 0.05). Additionally, left trunk lateral flexion was significantly higher in the BFRT Group compared to the TRT Group (P < 0.05).

Table 3. Core Muscle Strength Data.

Indicator (unit)	Group	Pre	Post
Trunk Flexion (Nm)	BFRT	276.22 ± 20.12	318.00 ± 33.98*
	TRT	280.37 ± 12.33	308.19 ± 60.12*
Trunk Extension (Nm)	BFRT	530.19 ± 71.25	612.78 ± 49.99*
	TRT	512.20 ± 69.85	582.12 ± 49.25*
Left Trunk Lateral Flexion (Nm)	BFRT	142.31 ± 21.23	214.17 ± 24.65*#
	TRT	143.22 ± 19.19	168.74 ± 16.66
Right Trunk Lateral Flexion (Nm)	BFRT	150.51 ± 18.12	199.15 ± 31.81*
	TRT	153.19 ± 21.25	172.15 ± 21.98*
Rotation to the Left (Nm)	BFRT	165.19 ± 24.25	192.15 ± 24.29*
	TRT	164.19 ± 22.65	172.21 ± 35.49*
Rotation to the Right (Nm)	BFRT	155.49 ± 30.19	191.71 ± 19.56*
	TRT	157.79 ± 34.16	161.41 ± 34.19

Use the "±" symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **BFRT** = Blood Flow Restriction Training, **TRT** = Traditional High-Intensity Resistance Training, *Different from pretest, significant at the .05 level. #Indicates a difference in comparison between groups ($P < 0.05$).

Table 4 shows that both Groups demonstrated significant improvements in left and right knee flexion. However, an increase in left and right knee extension was observed only in the BFRT Group ($P < 0.05$).

Table 4. Isokinetic Muscle Strength of Knee Joint Data.

Indicator (unit)	Group	Pre	Post
Left Knee Extension （Nm）	BFRT	279.59 ± 30.12	312.41 ± 26.15*
	TRT	271.12 ± 29.25	293.12 ± 21.51
Right Knee Extension （Nm）	BFRT	293.22 ± 19.69	306.59 ± 27.42*
	TRT	286.12 ± 21.21	294.61 ± 30.55
Left Knee Flexion （Nm）	BFRT	150.74 ± 40.17	169.17 ± 19.99*
	TRT	149.31 ± 19.11	160.11 ± 25.68*
Right Knee Flexion （Nm）	BFRT	155.75T ± 21.15	163.79 ± 21.16*
	TRT	152.19 ± 19.87	159.11 ± 19.89*

Use the "±" symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **BFRT** = Blood Flow Restriction Training, **TRT** = Traditional High-Intensity Resistance Training, *Different from pretest, significant at the .05 level.

Table 5 highlights that both Groups showed significant improvements in squat jump and standing long jump. However, increases in countermovement jump, 30-meter sprint time, and frequency speed of the kick test were observed only in the BFRT Group ($P < 0.05$).

Table 5. Sport Performance Data.

Indicator (unit)	Group	Pre	Post
Squat Jump (cm）	BFRT	34.10 ± 2.97	40.19 ± 4.99*
	TRT	33.98 ± 3.01	37.35 ± 5.61*
Counter Movement Jump (cm）	BFRT	42.14 ± 4.15	50.17 ± 3.19*
	TRT	41.95 ± 1.99	45.99 ± 7.18
30 M Sprint Run (s)	BFRT	4.15 ± 0.12	3.90 ± 0.11*
	TRT	4.12 ± 0.16	4.01 ± 0.11
Standing Long Jump (cm）	BFRT	251.20 ± 8.96	263.12 ± 7.25*
	TRT	252.11 ± 10.15	259.14 ± 8.99*
Frequency Speed of Kick Test (rep)	BFRT	11.36 ± 2.05	14.26 ± 2.12*
	TRT	11.85 ± 2.05	13.58 ± 2.98

Use the "±" symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **BFRT** = Blood Flow Restriction Training, TRT = Traditional High-Intensity Resistance Training, *Different from pretest, significant at the .05 level. #Indicates a difference in comparison between groups ($P < 0.05$).

DISCUSSION

The main findings of this study indicate that, in Taekwondo athletes, BFRT is more effective than TRT for improving body composition, flexibility, lower body strength, and overall athletic performance. In contrast, TRT appears to be better suited for increasing thigh size. These results indicate that BFRT is be a valuable training method for Taekwondo athletes who want to enhance agility, explosive power, and functional movement essential for high-speed kicks and rapid footwork. Meanwhile, TRT may be more beneficial for those prioritizing muscle hypertrophy in the thighs, which could contribute to greater stability and endurance during matches.

The significant reduction in body fat and increase in lean body mass and skeletal muscle mass observed in the BFRT Group align with previous research indicating that BFRT effectively enhances muscle hypertrophy and strength (7,13). For instance, a study published in Scientific Reports reported improvements in sprint performance following BFRT, suggesting its potential to enhance body composition and athletic performance (11). Both training methods resulted in significant increases in hip circumference, suggesting that both BFRT and TRT were effective for promoting hypertrophy in the lower body. However, an increase in left thigh circumference was observed only in the BFRT Group, indicating that BFRT may foster more uniform muscular adaptations across the lower body.

A key finding in this study is the significantly greater improvement in trunk flexion, trunk extension, lateral flexion, and rotation in the BFRT Group compared to TRT. The enhancement in these movements is crucial for taekwondo athletes, since trunk flexibility and strength play a pivotal role in executing powerful kicks and maintaining balance during complex maneuvers. BFRT's effectiveness in improving core strength and mobility might be attributed to the high metabolic demand it places on the muscles that lead to improved muscular endurance and flexibility (1).

Regarding joint function, both training Groups showed significant improvements in knee flexion, indicating enhanced knee flexor strength. However, only the BFRT Group demonstrated significant gains in knee extension strength, which is an important factor in executing powerful kicks. This advantage highlights the potential of BFRT in enhancing taekwondo-specific movements. In terms of explosive performance, both Groups improved in squat jump and standing long jump. However, only the BFRT Group showed significant enhancements in countermovement jump, 30-meter sprint time, and frequency speed of the kick test. These results suggest that BFRT may be more effective than TRT for developing explosive power and speed, which are key attributes for taekwondo athletes. The increased metabolic stress and subsequent hormonal responses induced by BFRT may contribute to these superior adaptations. These findings are consistent with previous research (3) indicating that BFRT can outperform traditional resistance training in improving strength, power, and speed over a short training period.

Limitations in this Study

This study has several limitations that should be acknowledged. First, the relatively small sample size may limit the generalizability of the findings. A larger cohort would provide more robust data and improve the reliability of the results. Second, the training period of 8 weeks, while sufficient to observe some adaptations, may not fully capture the long-term effects of BFRT and TRT. Future studies with extended durations are needed to confirm the sustainability of these improvements. Additionally, factors such as individual training history, recovery status, and dietary intake were not controlled, which could have influenced the outcomes. Further research should consider these limitations to provide a more comprehensive understanding of the effects of BFRT on athletic performance

CONCLUSIONS

Incorporating BFRT into the training regimens of elite taekwondo athletes appears to offer substantial benefits over traditional resistance training. The observed improvements in body composition, muscle hypertrophy, flexibility, joint function, and explosive performance highlight BFRT as a potent training modality. Future research should explore the long-term effects of BFRT and its potential integration with other training strategies to further optimize athletic performance.

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How Does Green Tea (*Camellia Sinensis*) Beverage Impact Post-Workout Recovery?

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ABSTRACT

Suksaard C, Ganogpichayagrai A. How Does Green Tea (*Camellia Sinensis*) Beverage Impact Post-Workout Recovery? The purpose of this study was to evaluate the effects of green tea drinking on recovery immediately after intense exercise on physiological and gastrointestinal (GI) symptoms in college triathletes. Thirteen males at an age of 20.82 ± 1.66 years with a VO_2max of 60.12 ± 10.15 ml/kg/min participated in a double-blind, crossover design that involved 2 conditions: (a) Green Tea Beverage Ingestion (GT); and (b) Placebo (PLA) following an endurance exercise protocol. The physiological measurements (HR, HRV, SBP, and DBP) were taken immediately post-exercise, and after 15 and 30 minutes of recovery. Measurements of recovery variables (muscle soreness and rating of perceived exertion) and GI symptoms (fullness, thirst, heartburn, and bloating) were taken at 5, 15, 30, and 60 minutes of recovery. The results showed that green tea consumption significantly relieved muscle soreness and reduced fatigue compared to the placebo. However, there were no significant differences in the participants' physiological measurements between the 2 conditions. The findings indicate that the consumption of green tea after exercise promoted recovery, relieved muscle soreness, and reduced fatigue by improving antioxidants, such as catechins and magnesium in male college triathletes.

Key Words: Fatigue, Green Tea, Muscle Soreness, Recovery

INTRODUCTION

Intense exercise can significantly impact the body, leading to dehydration, muscle glycogen depletion, fatigue, and delayed onset muscle soreness (DOMS) in exercise performance (4). These effects are common across various exercise types, including anaerobic, aerobic, strength training, and team sports. The recovery after the exercise workout is a crucial component of the training adaptation cycle that significantly enhances athletic performance, minimizes the risk of injury, and sustains general well-being (24). It is an important part of athletic training and performance. The recovery helps the body acquire its normal state, prevents injuries, and makes the most of physiological changes. It consists of a combination of nutritional, physical, and psychological strategies and, importantly, recovery with nutrition is important for optimizing athletic performance and facilitating muscle repair and glycogen replenishment (13,27).

In addition to macronutrients, carbohydrates, proteins, and fats, the micronutrients contain bioactive compounds, such as antioxidants, that support recovery by reducing inflammation and oxidative stress (35). Green tea is an ergogenic supplement that optimizes mitochondrial function and increases lipolysis and fatty acid metabolism, thereby reducing fatigue and improving endurance performance (12). Green tea comes from unfermented dried leaves of *Camellia Sinensis*. Black tea, green tea, and oolong tea are all made from the same plant, but they are prepared using different processing methods. The predominant constituents of green tea are polyphenols belonging to the family of catechins, mainly (–)-epigallocatechin gallate (EGCG), with lesser amounts of catechin (C), epicatechin (EC), epigallocatechin (EGC), and epicatechin gallate (ECG).

In addition, caffeine, theanine, theaflavins, and phenolic acids such as gallic acid are present in smaller quantities (9). A green tea beverage (250 mL) contains 50 to 100 mg of catechins and 30 to 40 mg of caffeine. Green tea is a rich source of antioxidants. The structural properties of green tea catechins play a role in their antioxidant function. The catechin content in green tea is higher than that of black tea due to the process. The functions of catechins are anti-inflammatory and antioxidant effects: scavenging of reactive oxygen species, inhibition of the formation of free radicals, and lipid peroxidation.

Green tea also contains an amino acid named L-theanine, which significantly modifies the effects of caffeine, reducing its stimulant effect, positively affecting alpha brain waves, improving cognitive functions, mood, and concentration, and additionally, decreasing blood pressure, which has a calming effect (15). Green tea has been shown to have potential benefits for sports recovery due to its antioxidant properties and potential anti-inflammatory effects. Green tea improves recovery from exercise-induced fatigue, reduces muscle damage, and also enhances the benefits of exercise on cardiovascular health and aerobic capacity (11). Therefore, the purpose of this study was to evaluate the effects of green tea drinking on recovery immediately after intense exercise.

METHODS

Subjects

Thirteen healthy male college triathletes participated in this study, ***Inclusion criteria*** stipulated that the participants must be competing in Triathlon international or national-level competitions within 2 years and pass the PAR-Q+ evaluation. Also, the participants needed a VO_2max higher than 45.4 ml/kg/min. The participants who met the inclusion criteria signed an informed consent form following the Declaration of Helsinki and agreed to voluntarily participate in the study. The study was approved by the Mae Fah Luang University Human Research Ethics Committee (approval number: 23096-18). The ***exclusion criteria*** were musculoskeletal injuries, allergy to tea or caffeine tolerance, or missing data on collection days.

Procedures

The present study was a double-blind, placebo-controlled, crossover design. During the 3 days before each trial, the participants were asked to reduce the volume of exercise training, record all food and beverage intake, and fast overnight for 8 hours. On the cycling performance test day, the participants attended the laboratory to perform the cycling performance, which was performed at the same time in every trial.

All the participants attended the Sports Physiology Laboratory at Mae Fae Luang University, Chiang Rai, Thailand 3 times, 7 days apart, starting at 7:00 a.m. First, the preliminary VO_2max participants completed orientation and performed VO_2max testing using graded exercise to exhaustion on a treadmill (Nautilus T916, Canada). Heart rate change was recorded using a heart rate monitor (Polar H10, USA). The test was started with a 3-minute warm-up at 3 km/hr that was increased by 1 km/hr every minute until the subject stopped running due to exhaustion.

Supplement

The participants were randomly assigned to recovery drinks immediately following the exercise, which was a 350 ml green tea beverage with no calories or a 350 ml placebo that contained water, green tea color, odor synthesis, no calories, and no catechins. The participants were asked to finish the drink within 5 minutes. No other food or drinks were allowed during the 60-minute recovery period.

Physiological Measurements

Heart rate change (HR) and heart rate variability (HRV) were recorded using a heart rate monitor (Polar H10, USA). Blood pressure was recorded using a heart rate monitor (Omron 7156, Japan).

Recovery Measurements

Rating of perceived exertion (RPE) was recorded using a Borg Scale (2). Delayed onset muscle soreness (DOMS) was recorded using a 100 mm visual analog scale, with 0 indicating no muscle soreness and 100 indicating impaired movement due to immediate muscle soreness at post-exercise, after 5 minutes, after 15 minutes, after 30 minutes and, after 60 minutes without an external noise factor, such as a telephone.

Gastrointestinal Measurements

The Gastrointestinal Symptom (GI) questionnaire was recorded using a scale. Fullness, Thirsty, Heartburn, Bloating scales were undertaken immediately post-exercise, after 5 minutes, after 15 minutes, after 30 minutes, and after 60 minutes.

Statistical Analyses

The sample size was chosen based on a power calculation (version 3.1.9.2; G*Power, Düsseldorf, Germany) with an effect size of 0.5 and a power of 0.8. Statistical testing was conducted using SPSS version 29.0 (Thomson Learning, Pacific Grove, CA) at an alpha level of $P < 0.05$ for all analyses. For physiological and GI symptom, the One-Way ANOVA was used to determine the differences between the trials. A Repeated ANOVA was used to analyze the within trials. The data were expressed as mean ± SD.

RESULTS

The 13 male participants were aged 20.82 ± 1.66 years, height 175.18 ± 4.26 cm, weight 74.73 ± 5.87 kg, and VO_2max 60.12 ± 10.15 ml/kg/min. The graded exercise to exhaustion test started with a 10-minute warm-up followed by graded exercise training at 50 watts, which was then increased to 35 watts every 3 minutes until exhaustion. The results are presented in Table 1. The participants were randomly assigned to the recovery drinks immediately following the exercise. There were no significant differences between the conditions for any of the measured variables.

Table 1. Physiological Variables.

Variables	Conditions							
	Green Tea (GT) (N = 13)				**Placebo** (PLA) (N = 13)			
	Rest	**After test**	**15 mins**	**30 mins**	**Rest**	**After test**	**15 mins**	**30 mins**
HR (beats·min^{-1})	63.18± 10.94	171.09± 12.96	92.09± 12.09	83.91± 11.71	68.18± 13.71	166.91± 15.88	85.55± 11.82	81.45± 12.72
HRV (ms)	86.45± 43.06	4.91± 1.92	29.09± 9.84	47.36± 14.28	85.91± 44.33	6.09± 2.98	39.64± 18.96	52.45± 19.59
SBP (mmHg)	124.00± 8.05	146.82± 13.10	119.73± 9.39	114.45± 7.45	124.36± 6.87	154.82± 20.87	112.27± 9.05	118.64± 11.47
DBP (mmHg)	75.36± 6.64	69.55± 10.83	73.36± 8.78	71.64± 6.05	75.18± 7.82	74.91± 12.37	81.09± 30.63	71.82± 6.66

*Significant level at ($P < 0.05$). Abbreviations: **HR** = Heart Rate, **HRV** = Heart Rate Variability, **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure.

For the physiological measurements, RPE and DOMS are recorded as shown in Table 2. They indicate impaired movement due to muscle soreness immediately post-exercise, after 5 minutes, after 15 minutes, after 30 minutes and, after 60 minutes without an external noise factor.

Table 2. Recovery Variables.

Variables	Conditions			
	Delayed Onset Muscle Soreness (N = 13)		Rating of Perceived Exertion (N = 13)	
	GT	PLA	GT	PLA
After	6.55±3.05	6.55±2.50	8.36±1.50	8.09±1.92
5 mins	3.91±1.97	4.09±1.70	4.91±1.30	4.73±1.27
15 mins	2.73±1.62	2.82±1.54	3.00±1.34	3.18±0.98
30 mins	1.64±1.21	2.09±1.64	1.82±0.75	2.55±0.82*
60 mins	0.36±0.50	1.73±1.74*	1.09±0.30	1.64±0.67*

*Significant level at ($P < 0.05$). Between Groups.

For gastrointestinal symptoms, Fullness, Thirsty, Heartburn, and Bloating scales were determined immediately post-exercise, after 5 minutes, after 15 minutes, after 30 minutes, and after 60 minutes. The results are shown in Table 3.

Table 3. Gastrointestinal Symptoms.

Variables	Conditions							
	Fullness (N = 13)		Thirsty (N = 13)		Heartburn (N = 13)		Bloating (N = 13)	
	GT	PLA	GT	PLA	GT	PLA	GT	PLA
After Test	3.45±2.50	2.82±2.23	3.55±2.02	3.00±2.14	0.27±0.65	0.36±1.20	0.18±0.60	0.45±1.51
5 mins	4.00±2.32	3.91±1.97	5.45±1.76	4.00±2.05	0.27±0.65	0.18±0.60	0.18±0.60	0.36±1.21
15 mins	3.55±1.92	3.55±1.63	4.18±1.66	3.73±1.42	0.09±0.30	0.09±0.30	0.09±0.30	0.18±0.60
30 mins	2.91±1.92	2.91±1.70	3.64±1.50	4.09±1.51	0.09±0.30	0.00±0.00	0.09±0.30	0.00±0.00
60 mins	3.55±1.63	3.55±1.21	3.27±1.62	3.09±1.92	0.09±0.30	0.00±0.00	0.00±0.00	0.00±0.00

*Significant level at ($P < 0.05$), Between Groups.

DISCUSSION

The consumption of green tea has potential benefits for athletes in the long term. It reduces muscle damage and oxidative stress, which supports a faster recovery while also enhancing neuromuscular and cardiovascular performance (18). The purpose of this study was to evaluate the acute effects of green tea drinking on the recovery period in the physiological and GI symptoms. The acute effects of physiological variables were HR, HRV, SBP, and DBP. Thirteen male triathlon athletes aged 20.82 ± 1.66 years participated in the study. The research findings indicated that there were no statistically significant differences in HR, HRV, and blood pressure when comparing GT and PLA after intense exercise.

Water intake after exercise accelerates the reduction in heart rate during the recovery period. Paula-Ribeiro et al. (23) observed that water consumption led to a more rapid decrease in heart rate and blood pressure post-exercise. Water intake post-exercise enhances HRV, an indicator of autonomic nervous system balance. Also, according to Peçanha et al. (25), the participants who consumed water after exercise exhibited higher HRV values throughout the recovery period, which indicated an improvement in parasympathetic activity and cardiovascular recovery.

Drinking green tea shows no statistically significant difference when compared to drinking plain water. However, green tea stimulates the heart rate, depending on the individual and the amount consumed. Green tea contains caffeine, which is a stimulant that can increase heart rate by stimulating the central nervous system (20). Caffeine can promote the release of adrenaline (epinephrine), which increases heart rate and blood pressure. After exercise, the heart rate is usually faster due to antagonizing adenosine receptors, leading to enhanced neurotransmission of catecholamines.

A large amount of muscle load is found after intense exercise, and microtears happen. This process often leads to muscle pain, a normal physiological reaction that plays a key role in stimulating muscle adaptation and long-term strengthening (30). Muscle soreness, which is commonly known as Delayed Onset Muscle Soreness (DOMS) occurs approximately 24 to 48 hours after exercise. DOMS indicates that the muscles are undergoing adaptation and recovery processes (5,10). However, muscle soreness may also result from dehydration or deficiencies in essential nutrients, such as magnesium or potassium that can cause muscle cramps and discomfort (19,34). A slight increase in pain scale immediately after testing, followed by a decrease within 1 hour after intense exercise, is considered normal and beneficial, as it reflects appropriate muscle activation and recovery (5,21).

This study indicates the level of muscle soreness at 5-, 15-, 30-, and 60-minutes post-exercise can help track the progression of pain over time. Muscle soreness levels measured 60 minutes after consuming green tea by the GT Group showed a statistically significant difference compared to the placebo (PLA) Group ($P = 0.021$). Green tea consumption can help restore muscle and reduce muscle pain, which may be due to the high magnesium content. Green tea has been reported to contain approximately 1885 micrograms of magnesium per 100 milliliters of extract (16). Magnesium in green tea enhances antioxidant capacity that contributes to the prevention of oxidative stress and inflammation (3,16).

Furthermore, magnesium is essential for ATP production, the primary cellular energy currency critical for muscle contraction and relaxation, as it acts as a cofactor in enzymatic reactions involved in ATP synthesis. This supports muscle function and reduces fatigue during exercise (1). In athletes, magnesium supplementation has been shown to improve exercise performance by increasing glucose availability and decreasing lactate accumulation, which may delay muscle fatigue and enhance endurance performance (36). The long-term supplementation with green tea has been shown to reduce creatine kinase enzyme levels following exercise (14,15,31,32).

The present study found that the rating of perceived exertion (RPE) was significantly different after consuming GT and PLA for 30 and 60 minutes (P = 0.042, 0.024, respectively). The results indicate that green tea can reduce fatigue following exercise more effectively than water. This effect may be attributed to the high content of catechins in green tea. Catechins enhance skeletal muscle performance by promoting mitochondrial biogenesis and protein synthesis, which are critical for muscle function and endurance. This mechanism is particularly beneficial in conditions associated with muscle dysfunction and exercise-induced fatigue (17). In addition, in the context of cumulative fatigue circumstances, supplementing with green tea extracts that are high in catechins, protected neurological function and decreased muscle damage, indicating increased athlete performance and recovery (18). Catechins can reduce inflammation-related muscle damage and fatigue through their anti-inflammatory properties, which can maintain the integrity and function of muscles (28).

Gastrointestinal (GI) symptoms are frequently reported following exercise, with abdominal fullness being a common complaint. These symptoms can result from consuming a heavy meal before exercise or exercise at a high-intensity level, which increases blood flow to skeletal muscles and reduces splanchnic blood flow, causing a reduction in gastrointestinal function (7,33). Thirst is a common physiological response indicating fluid or electrolyte loss, which if not adequate can lead to fatigue and impaired exercise performance (6,29). Heartburn, a burning sensation in the chest, may result from gastroesophageal reflux, which can be triggered by pre-exercise food intake or specific exercise postures that increase intra-abdominal pressure (8,26). Bloating, for example, may occur from consuming hard-to-digest foods before exercise or it may be due to the physiological adaptations during physical activity, such as decreased gastrointestinal blood flow and altered digestive function (7,33).

The results indicated no statistically significant differences between the Green Tea Group and the Placebo (water) Group. Therefore, the consumption of either green tea or water 60 minutes post-exercise resulted in only mild levels of abdominal fullness and thirst (Fullness: 3.55 ± 1.63 for GT vs. 2.91 ± 1.70 for PLA; Thirst: 3.27 ± 1.62 for Green Tea vs. 3.09 ± 1.92 for Placebo). Additionally, no symptoms of heartburn or bloating in either Group was reported following post-exercise beverage consumption.

CONCLUSIONS

The consumption of green tea after exercise may be beneficial for the recovery process, relieve muscle soreness, and reduce fatigue. This effect might result from compounds in green tea that increase the levels of antioxidants in the body, such as catechins and magnesium, which contribute to the prevention of oxidative stress and inflammation, the reduction of muscle pain, the delay in the onset of fatigue, and improvement in muscular endurance. The research results show the potential of green tea as an alternative post-exercise recovery beverage for athletes, particularly in relieving muscle soreness and reducing fatigue immediately after intense exercise.

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Associations between Core Muscle Flexibility and Respiratory Function in Patients with Asthma

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ABSTRACT

Jaroensukwimon N, Klaewsongkram J, Mickleborough TD, Tongtako W. Associations between Core Muscle Flexibility and Respiratory Function in Patients with Asthma. This study examined the relationship between core muscle flexibility and pulmonary function in adults with asthma. Thirty participants with physician-diagnosed asthma underwent assessments of lung function, respiratory muscle strength, core flexibility, and asthma symptoms. Pearson's correlation analysis revealed that trunk and neck extension were significantly associated with key pulmonary parameters (e.g., PEF, FVC, FEV1/FVC, MIP, MEP) and Mini AQLQ scores ($P < 0.05$). Notably, FEV1/FVC and MEP correlated with all flexibility measures. These findings suggest that greater core flexibility, especially in trunk and neck extension, is linked to better pulmonary function and respiratory strength in adults with asthma.

Key Words: BMI, Exercise, Metabolism, VO_2 Max

INTRODUCTION

Asthma is a chronic respiratory condition characterized by variable airflow obstruction and symptoms such as wheezing, chest tightness, coughing, and shortness of breath that can significantly interfere with daily activities in individuals with severe forms of the disease (2, 13,15). Exertional dyspnea in asthma can vary in both severity and duration, and often arises from multiple contributing factors. These may include ventilatory limitations, impaired gas exchange, dysfunction of the pulmonary vasculature or heart, abnormalities in limb muscle function, and the presence of other comorbid conditions, either independently or in combination (5,22).

Cross-sectional studies indicate that both children and adults with asthma typically exhibit reduced lung function compared to individuals without asthma, particularly when symptoms are persistent. In adults, this decline in lung function tends to be more pronounced over time (7). Fixed airway obstruction and the accelerated deterioration of lung capacity are believed to result from structural alterations in the airways associated with chronic inflammation, a process commonly referred to as airway remodeling (3,20). Lunardi et al. (10) demonstrated that individuals with mild to severe persistent asthma often exhibit muscle shortening and postural abnormalities, particularly affecting the chest wall, trunk, and muscles involved in respiration. Asthmatic patients tend to overuse their respiratory muscles to compensate for airflow obstruction, leading to adaptive hypertrophy. Over time, the continuous strain on these muscles causes them to shorten and lose flexibility (2,19). Therefore, assessing core muscle function is essential for effective planning, as well as for tracking progress and outcomes aimed at alleviating asthma symptoms.

Core muscles assist in both expiration and inspiration by supporting chest wall alignment and diaphragmatic function (14). Impaired muscle function or fatigue during hyperpnea can increase the workload of the thoracic muscles and intensify breathlessness. The diaphragm and abdominal muscles may experience contractile fatigue, which can increase the workload of the thoracic muscles and, in turn, heighten the perception of dyspnea (12,17). Core muscles work in coordination with the lateral abdominal muscles and the diaphragm to regulate intra-abdominal pressure and provide trunk stability (1).

Previous research has indicated that core muscles can influence lung function. Hence, the development of the core muscles is vital for the proper functioning of the cardiopulmonary system (8). Flexibility is crucial for sustaining a healthy range of motion in the joints. Engaging in flexibility exercises can help prevent musculoskeletal injuries by stretching tight soft tissues and promoting proper, efficient joint movement (1). In patients with asthma, investigating core muscle flexibility is important, given that the muscles may play a role in lung function, and the symptom expression may offer a valuable insight into its potential relationship with pulmonary function and asthma severity. This point has received limited attention in the previous research.

We hypothesize that in adults with asthma, alterations in respiratory mechanics and reduced core muscle flexibility are associated with decreased pulmonary function that contribute to the worsening of asthma symptoms. Therefore, the purpose of this study was to investigate the correlation between core muscle flexibility and pulmonary function in individuals with asthma.

METHODS

Subjects

The study protocol was approved by the Research Ethics Review Committee for Research Involving Human Subjects at Chulalongkorn University. The sample size of the subjects was determined by the Bujang and Baharum (4) with an alpha error of 0.05 and a power of 0.80, baseline correlation (R0) of 0, and an alternative correlation (R1) of 0.7. A minimum of 24 subjects were required for this study, which included 30 asthmatic patients 18 to 65 years of age from King Chulalongkorn memorial hospital, Thailand. The ***inclusion criteria*** were physician-diagnosed asthma for at least 6 months. The ***exclusion criteria*** included subjects with known chronic obstructive pulmonary disorder (COPD), pulmonary tuberculosis, or cardiovascular diseases. Additionally, the participants needed to be able to communicate and understand verbal and written Thai, and they could not be users of tobacco. Also, they were required to have not engaged in a regular exercise program for at least 6 months prior to the study.

Procedures

Once the participants met these criteria, appointments were scheduled for testing and data collection. A written informed consent was obtained from the participants before their involvement, which included an hour assessment of their physiological characteristics, pulmonary functions, respiratory muscle strength, muscle flexibility, and asthma control questionnaires.

Pulmonary Function Testing

The projected values in liters of FVC, FEV1, and MVV were measured using a computerized spirometer (SpirobankG) in accordance with the American Thoracic Society's pulmonary function test recommendations. The participants sat on a chair while wearing a nasal clip. They performed 3 cycles of slow, normal breathing before demonstrating forced inspiration and expiration and then returning to normal breathing. For the MVV maneuver, the participants were instructed to inhale and exhale quickly and forcefully for 15 seconds.

Respiratory Muscle Strength Testing

Respiratory muscle strength was measured by using a portable handheld mouth pressure meter (Micro RPM England). The participants were instructed to exhale until they felt no air left in their lungs (beginning at the functional residual capacity (FRC) threshold) for the MIP assessment. Then, they placed the instrument in their mouth and breathed for 1 to 2 seconds. They were instructed to inhale until their lungs were completely full of air for the MEP measurement (starting with the total lung capacity [TLC] point). Then, they held the device in their lips for 1 to 2 seconds and exhaled strongly.

Core Muscle Flexibility Testing

Trunk Flexion

To assess trunk flexion, the participants were first instructed to stand upright with feet shoulder-width apart and arms relaxed at their sides. Then, the researcher used a measuring tape to measure the distance from the C7 vertebra to the S1 vertebra and recorded this value as the baseline. Next, the participants were instructed to slowly bend forward at the waist as far as possible, keeping their legs straight and avoiding any flexion of the knees. Once maximum waist flexion was reached, the researcher measured the distance again from C7 to S1 using the same method and recorded the second value. The difference between the measurement in the upright position and the measurement in the flexed position was then calculated.

Trunk Extension

To evaluate trunk extension, the participants were instructed to stand upright with their feet shoulder-width apart and arms resting at the sides. The researcher used a measuring tape to determine the distance between the C7 and S1 vertebrae and recorded this as the baseline measurement. Then the participants were asked to slowly extend their trunk backward as far as possible without engaging the hips or rotating the torso. At the point of maximum extension, the distance from C7 to S1 was measured again using the same method, and the new value was recorded. The difference between the upright and the extended position measurements was calculated.

Neck Flexion

To assess neck flexion, the participants were instructed to stand upright in a relaxed posture. The researcher positioned the pivot point of a goniometer at the external auditory meatus of the participant. Then, the participants were instructed to slowly flex their neck forward, bringing the chin as close to the chest as possible without lifting the shoulders. The researcher aligned one arm of the goniometer with the vertical midline of the participant’s body and the other arm with the tip of the nose to measure the angle of movement. The degree of neck flexion was measured and recorded.

Neck Extension

To evaluate neck extension, the participants were instructed to stand upright in a relaxed posture. Then, they were asked to slowly extend their neck by tilting their head backward as far as possible, without moving the shoulders or upper back. The researcher positioned the pivot point of a goniometer at the external auditory meatus (ear hole). One arm of the goniometer was aligned with the vertical midline of the participant’s body, and the other arm was aligned with the tip of the nose to measure the angle of neck extension. The degree of movement was measured and recorded.

Asthma Control Test

The Asthma Control Test (ACT) is a patient self-administered questionnaire designed to identify individuals with poorly controlled asthma. The test consists of 5 items assessing asthma symptoms, use of rescue medications, and the impact of asthma on daily functioning over the past 4 weeks. Scores range from 5 to 25, with higher scores indicating greater asthma control. A total score greater than 19 suggests well-controlled asthma, while scores of 19 or lower may indicate suboptimal control and the need for further evaluation or a treatment adjustment.

The Thai Mini AQLQ Questionnaire

The Thai Mini AQLQ questionnaire consists of 15 items divided into 4 categories: Symptoms (5 items); Environment (3 items); Emotion (3 items); and Activity (4 items). The overall score is calculated from an average score of all 15 items. Scores range from 15 to 75 with the higher scores representing a better quality of life.

Statistical Analyses

The data were analyzed using the SPSS version 28 for Windows (SPSS Inc., Chicago, USA). Pearson's correlation was used to analyze the relationship between pulmonary function and core muscle stability. The differences were considered significant at $P < 0.05$. Descriptive statistics were presented as mean ± SD.

RESULTS

The baseline characteristics of the asthma patients (N = 30) are presented in Table 1.

Table 1. Physiological Data of the Subjects.

Variables	Asthma Patients (N = 30)
Age (year)	37.60 ± 11.65
BW (kg)	67.19 ± 16.60
HR (beats·min^{-1})	81.60 ± 11.96
SBP (mmHg)	122.27 ± 14.64
DBP (mmHg)	69.43 ± 11.23

The data are presented as mean ± SD. **BW** = Body Weight, **HR** = Heart Rate, **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure.

The mean and standard deviation of respiratory function, core muscle flexibility, and symptom scores among asthma patients are presented in Table 2.

Table 2. The Mean and Standard Deviation of Respiratory Function, Core Muscle Flexibility, and Symptoms.

Variables	Asthma Patients (N = 30)
RESPIRATORY FUNCTION	
PEF (L·min^{-1})	4.53 ± 0.97
FVC (L)	2.99 ± 0.65
FEV1 (L)	2.73 ± 0.71
FEV1/FVC (%)	86.54 ± 4.08
FEF25-75% (L·sec^{-1})	3.63 ± 1.12
MVV (L·min^{-1})	83.29 ± 11.27
MIP (cmH_2O)	83.17 ± 12.24
MEP (cmH_2O)	81.58 ± 7.36
CORE MUSCLE FLEXIBILITY	
Trunk Flexion (inch)	2.63 ± 0.55
Trunk Extension (inch)	2.07 ± 0.86
Neck Flexion (inch)	45.17 ± 5.02
Neck Extension (inch)	27.67 ± 2.15
SYMPTOMS	
ACT (scores)	21.37 ± 2.73
Mini AQLQ (scores)	51.37 ± 7.29

The data are presented as mean ± SD. **PEF** = Peak Expiratory Flow, **FVC** = Forced Vital Capacity, **FEV1** = Forced Expiratory Volume in 1 Second, **FEV25-75%** = Forced Expiratory Flow at 25 – 75%, and **MVV** = Maximum Voluntary Ventilation, **MIP** = Maximum Inspiratory Pressure, **MEP** = Maximum Expiratory Pressure, **ACT** = Asthma Control Test, **Mini AQLQ** = Mini Asthma Quality of Life Questionnaire.

Table 3 presents the correlation coefficients between core muscle flexibility, respiratory function, and symptom scores in patients with asthma. Trunk extension showed significant positive correlations with several respiratory function parameters, including PEF, MVV, and MEP. It was also significantly correlated with ACT scores.

Neck extension was significantly positively correlated with PEF, FVC, FEV1/FVC, MIP, and MEP. Additionally, it showed a significant positive correlation with Mini AQLQ scores. FEV1/FVC ratio was significantly correlated with all measures of core muscle flexibility, including trunk flexion, trunk extension, neck flexion, and neck extension. MEP was significantly associated with all core flexibility variables: trunk flexion, trunk extension, neck flexion, and neck extension.

Table 3. The Correlation Among Core Muscle Flexibility, Respiratory Function, and Symptoms in Patient with Asthma.

Variables		Trunk Flexion	Trunk Extension	Neck Flexion	Neck Extension
PEF	r	0.157	0.445	0.266	0.391
	P	0.407	0.014*	0.156	0.033*
FVC	r	0.187	0.406	0.174	0.366
	P	0.322	0.026*	0.357	0.047*
FEV1	r	0.028	0.379	0.163	0.235
	P	0.883	0.039*	0.388	0.211
FEV1/FVC	r	0.494	0.508	0.522	0.430
	P	0.006*	0.004*	0.003*	0.018*
FEF25-75%	r	0.032	0.395	0.135	0.172
	P	0.865	0.031*	0.478	0.364
MVV	r	0.227	0.460	0.208	0.286
	P	0.228	0.011*	0.269	0.126
MIP	r	0.161	0.557	0.315	0.423
	P	0.395	0.001*	0.090	0.020*
MEP	r	0.437	0.641	0.516	0.531
	P	0.016*	0.001*	0.004*	0.003*
ACT	r	0.205	0.396	0.259	-0.425
	P	0.278	0.030*	0.167	0.190
Mini AQLQ	r	0.017	0.333	0.358	0.372
	P	0.928	0.072	0.052	0.043*

The data are presented as mean ± SD. *P < 0.05; **PEF** = Peak Expiratory Flow, **FVC** = Forced Vital Capacity, **FEV1** = Forced Expiratory Volume in 1 Second, **FEV25-75%** = Forced Expiratory Flow at 25 – 75%, and **MVV** = Maximum Voluntary Ventilation, **MIP** = Maximum Inspiratory Pressure, **MEP** =

Maximum Expiratory Pressure, **ACT** = Asthma Control Test, **Mini AQLQ** = Mini Asthma Quality of Life Questionnaire.

DISCUSSION

The findings from this study reveal significant positive correlations between core muscle flexibility and respiratory function in patients with asthma. Notably, trunk extension showed strong associations with key respiratory parameters, including PEF, FVC, FEV1, FEV1/FVC, FEF25-75%, MVV, MIP, and MEP. These relationships suggest that greater flexibility in the trunk extensors may contribute to improved pulmonary mechanics and respiratory muscle performance. This aligns with previous research indicating that muscle flexibility improved the length-tension relationship of accessory muscles and can enhance breathing mechanics and efficiency (18).

Similarly, neck extension demonstrated significant positive correlations with several respiratory function indices—PEF, FVC, FEV1/FVC, MIP, and MEP—suggesting a supportive role of cervical mobility in respiratory efficiency. These findings support the notion that postural alignment and cervical spine flexibility may influence upper airway patency and respiratory muscle activation, which are crucial in patients with asthma. Improving muscle flexibility stimulates muscle spindle activity, enhances the viscoelastic properties of the respiratory muscles, and increases their compliance. These adaptations contribute to improved generation of MIP. In individuals with chronic respiratory diseases, MIP serves as an important indicator of respiratory muscle strength, supporting more efficient breathing, greater energy availability, and improved functional capacity—ultimately leading to better overall respiratory function (16).

Importantly, the FEV1/FVC ratio and MEP were positively correlated with all measures of core muscle flexibility, indicating a robust relationship between musculoskeletal function and pulmonary performance. The previous research indicated that increasing FEV1/FVC was associated with decreasing odds for respiratory symptoms (11,21). The FEV1/FVC ratio is a key marker in diagnosing and monitoring obstructive lung diseases (6,9), and its association with core flexibility highlights the potential clinical relevance of musculoskeletal assessments in asthma management. The consistent correlation of MEP with trunk and neck flexibility further suggests that expiratory muscle strength is closely tied to the extensibility and alignment of core structures, which may impact cough efficiency and airway clearance.

In addition, trunk extension was significantly associated with better asthma control as measured by the ACT score, while neck extension was positively correlated with quality of life (Mini AQLQ scores). These associations underscore the broader impact of musculoskeletal flexibility not only on physiological function but also on perceived symptom control and daily living. This aligns with previous research showing that adults with severe asthma have worse core function than their control counterparts. Moreover, the study indicated that as core function decreases, breathing symptoms increase (14). Together, these findings highlight the importance of maintaining both flexibility and core stability in the management of asthma, suggesting that targeted physical interventions may play a vital role in improving both clinical outcomes and quality of life in this population.

Collectively, these findings support the integration of core flexibility and postural training into pulmonary rehabilitation programs for asthma patients. Enhancing flexibility may contribute to better respiratory function and symptom management, thus improving overall quality of life.

CONCLUSIONS

This study demonstrates significant positive correlations between core muscle flexibility and respiratory function in patients with asthma. Flexibility in both the trunk and neck, particularly trunk extension, was associated with improved pulmonary function, respiratory muscle strength, asthma control, and quality of life. These findings highlight the potential clinical value of incorporating core flexibility and postural training into asthma rehabilitation programs. Enhancing musculoskeletal flexibility may serve as a complementary approach to improving respiratory efficiency and symptom management, ultimately contributing to better health outcomes in individuals with asthma.

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The Correlations between Sudoscan® Parameters and Neuropathic Symptoms in Diabetes

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ABSTRACT

Koksungnoen T, Menz HB, Naewwongse W, Khongprasert S. The Correlations between Sudoscan Parameters and Neuropathic Symptoms in Diabetes. The purpose of this study was to investigate the correlation between electrochemical skin conductance (ESC) measured by Sudoscan and neuropathic symptoms in patients with diabetes. A total of 44 patients with diabetes (mean age = 67.23 ± 4.29 years, HbA1c = 7.53 ± 0.88 %) underwent comprehensive assessments using the Michigan Neuropathy Screening Instrument (MNSI) and Sudoscan. Additionally, neuropathic symptoms were evaluated using the Neuropathy Symptom Score (NSS), Short-form McGill Pain Questionnaire (SF-MPQ), Foot Pain Manikin, and 10 g monofilament test. Pearson correlation analysis was performed to determine associations between ESC and neuropathic symptom measures. Significant negative correlations were observed between ESC and NSS ($r = -0.583$, $P < 0.001$), McGill Pain Questionnaire scores ($r = -0.401$, $P < 0.007$), Foot Pain Manikin scores ($r = -0.411$, $P < 0.006$), and 10 g monofilament test results ($r = -0.394$, $P < 0.008$). The results highlight a strong correlation between Sudoscan parameters and clinical neuropathic symptoms, suggesting its potential as a non-invasive tool for assessing both small and large fiber impairment in diabetes. Future research should explore longitudinal changes in ESC to further elucidate its prognostic value in neuropathy progression.

Key Words: Electrochemical Skin Conductance, Sudoscan, Diabetic Neuropathy, Neuropathy Symptom Score

INTRODUCTION

Diabetic peripheral neuropathy (DPN) is one of the most common and debilitating complications of diabetes mellitus, occurring in up to 50% of long-standing diabetic patients (15). It is characterized by progressive damage to the peripheral nervous system, leading to sensory, motor, and autonomic dysfunction. Among these, small fiber neuropathy (SFN) is often the earliest manifestation, resulting in pain, burning, numbness, tingling, paresthesia, and autonomic dysfunction, while large fiber involvement leads to sensory loss, proprioceptive deficits, and impaired protective sensation (20). Without timely intervention, these neuropathic impairments can significantly increase the risk of foot ulceration, infection, and ultimately lower limb amputation (19).

For proper intervention and care, it is very important to detect neuropathy early. Traditional diagnostic approaches include nerve conduction studies (NCS), the 10 g monofilament test, and vibration perception threshold (VPT), predominantly evaluate large fiber function and do not identify early small fiber injury (6). Skin biopsy with intraepidermal nerve fiber density (IENFD) measurement is considered the gold standard for diagnosing small fiber neuropathy, but its invasive nature and high cost limit its widespread clinical use (10). Sudomotor function assessment has developed into a viable, non-invasive technique for identifying small fiber dysfunction, given that sweat gland innervation is facilitated by thin, unmyelinated autonomic nerve fibers (17).

Sudoscan® is an innovative, non-invasive device designed to assess electrochemical skin conductance (ESC), a marker of sudomotor function. ESC reflects the capacity of sweat glands to secrete chloride ions in response to an electrical stimulus, thereby providing an indirect assessment of autonomic small fiber integrity (4). Previous studies have demonstrated that reduced ESC values correlate with neuropathy severity, and Sudoscan has been proposed as a potential screening tool for early DPN detection (2). The device has been shown to provide rapid and reproducible measurements with good sensitivity for detecting autonomic dysfunction in diabetic patients (16).

Although Sudoscan has been increasingly studied in diabetes research, gaps remain in understanding how ESC correlates with validated neuropathic symptom scales and clinical measures of diabetic neuropathy. Most existing studies have focused on the association between ESC and objective measures of nerve function, such as NCS and quantitative sensory testing (QST) (18). Nevertheless, limited research has investigated the correlation between Sudoscan-derived ESC and subjective neuropathic symptoms, including pain intensity, numbness, and functional limitations (16).

Since neuropathic pain and sensory abnormalities significantly influence the quality of life in diabetes patients, it is essential to examine whether Sudoscan characteristics correlate with clinically important patient-reported outcomes. The lack of research correlating Sudoscan with validated neuropathic symptom scales presents a significant gap in the literature. While Sudoscan has demonstrated potential as a screening tool for early DPN detection, its ability to reflect the severity of neuropathic symptoms and functional impairments remains unclear. Understanding these relationships could enhance the clinical utility of Sudoscan in routine neuropathy screening and improve its role in patient-centered diabetes care.

The purpose of this study was to investigate the relationship between Sudoscan-derived ESC and various neuropathic symptom measures, including the Neuropathy Symptom Score (NSS), Short-form McGill Pain Questionnaire (SF-MPQ), Foot Pain Manikin (MANIKIN), and

10 g monofilament test. By identifying these correlations, this research seeks to enhance the diagnostic value of Sudoscan in assessing diabetic neuropathy and provide further insights into its clinical applicability. Additionally, this study may contribute to improving screening protocols for DPN, facilitating earlier intervention strategies for the prevention of disease progression and associated complications.

METHODS

Subjects

A total of 44 individuals with diabetes (mean age = 67.23 ± 4.29 years; mean HbA1c = 7.53 ± 0.88%) were recruited from the outpatient diabetes clinic at King Chulalongkorn Memorial Hospital, Bangkok, Thailand. The study protocol was reviewed and approved by the Institutional Review Board (IRB) of the Faculty of Medicine, Chulalongkorn University (Approval No. [015/65]), under an expedited review process prior to participant enrollment. The eligible participants were required to be aged 60 years or older with a confirmed clinical diagnosis of diabetes mellitus.

The exclusion criteria included the presence of non-diabetic neuropathy, any severe comorbid conditions that could independently affect peripheral nerve function (e.g., end-stage renal disease, active malignancy, or neurological disorders), or cognitive or communication impairments preventing informed consent. All the participants provided written informed consent before the commencement of data collection.

Procedures

The participants underwent a series of standardized neuropathy assessments to evaluate sudomotor function, small fiber dysfunction, and large fiber impairment. All assessments were conducted in a single testing session in a controlled clinical environment. Prior to testing, examiners provided instructions and ensured participants understood each procedure.

Electrochemical Skin Conductance (ESC)

ESC was assessed using Sudoscan, a non-invasive device that evaluates sudomotor function by measuring skin conductance in response to a low-voltage electrical stimulus (4). The participants placed their hands and feet on stainless steel electrodes, and ESC values (measured in microsiemens, μS) were recorded separately for the hands and feet. The test lasted approximately 3 minutes, and lower ESC values indicated greater impairment in sudomotor function. Only the feet were assessed, as sudomotor dysfunction in the feet is a key indicator of diabetic peripheral neuropathy (DPN) severity.

Neuropathy Symptom Score (NSS)

The Neuropathy Symptom Score (NSS) was used to quantify the severity of neuropathic symptoms (7). The participants responded to a series of questions assessing pain, numbness, tingling, burning, weakness, and autonomic symptoms associated with diabetic neuropathy. A higher NSS score indicated more severe symptoms.

Short-form McGill Pain Questionnaire (SF-MPQ)

The McGill Pain Questionnaire was administered to assess pain characteristics related to small fiber dysfunction (11). The participants were asked to describe the quality, intensity, and location of their pain using a standardized word descriptor list. For this study, only parts 1 and 2 of the SF-MPQ were used, which assess the sensory and affective dimensions of pain, while the evaluative scale (part 3) was not included. The Pain Rating Index (PRI) score was calculated from the responses in parts 1 and 2, with higher scores indicating greater pain severity.

Foot Pain Manikin (Manikin)

The Foot Pain Manikin was used to provide a visual representation of pain distribution in the lower extremities. The participants were given a diagram of the foot and instructed to shade areas where they experienced pain, discomfort, or abnormal sensations. The total number of shaded regions was recorded as an indicator of pain extent and localization (5).

10 g Monofilament Test

The 10 g monofilament test was used to assess protective sensation and large fiber function (14). A 10 g Semmes-Weinstein monofilament was applied to ten standard plantar sites on each foot. The participants were asked to indicate when they could feel the monofilament's pressure. Each insensate or abnormal response at a tested site was recorded as one point. All assessments were performed under standardized settings, with a qualified examiner guaranteeing uniform administration and participant safety during the testing procedure. The comprehensive neuropathy assessment required roughly 30 minutes for each participant.

Statistical Analyses

Data analysis was performed utilizing IBM SPSS Statistics version 28.0 (Armonk, NY: IBM Corp.). Pearson correlation analysis was conducted to investigate the associations between electrochemical skin conductance (ESC) and neuropathic symptom metrics. Descriptive statistics, such as mean and standard deviation, were employed to encapsulate the sample demographics and outcome factors. All statistical tests were two-tailed, with an alpha level of 0.05 to determine significance.

RESULTS

A total of 44 participants (38 females and 6 males) with diabetic peripheral neuropathy (DPN) were included in the study. The mean age for the female participants was 67.08 years (SD = 4.45), while for the males, it was 68.17 years (SD = 3.18). The mean height was 155.82 cm (SD = 4.97) for the females and 162.16 cm (SD = 8.06) for the males. In terms of body weight, the female participants had a mean weight of 56.72 kg (SD = 9.27); whereas, the male participants had a higher mean weight of 65.00 kg (SD = 13.02). Regarding glycemic control, the mean fasting blood glucose (FBG) level was 134.00 mg/dL (SD = 20.15) in the females and 132.50 mg/dL (SD = 11.53) in the males. The mean HbA1c level was 7.56% (SD = 0.89) for the females and 7.35% (SD = 0.85) for the males. A summary of demographic characteristics is presented in Table 1.

Table 1. Demographic Characteristics of the Participants with Diabetic Peripheral Neuropathy.

Characteristics	**DPN** (N = 44)	**Female** (N = 38)	**Male** (N = 6)
Age (year) M ± SD	67.23 ± 4.29	67.08 ± 4.45	68.17 ± 3.18
Height (cm) M ± SD	156.69 ± 5.80	155.82 ± 4.97	162.16 ± 8.06
Weight (cm) M ± SD	57.85 ± 10.10	56.72 ± 9.27	65.00 ± 13.02
FBG (mg/dL) M ± SD	133.80 ± 19.11	134.00 ± 20.15	132.50 ± 11.53
HbA1c (%) M ± SD	7.53 ± 0.88	7.56 ± 0.89	7.35 ± 0.85

Abbreviations: M = Mean, SD = Standard Deviation, FPG = Fasting Plasma Glucose, HgA1c = Hemoglobin A1C, cm = centimeter, mg/dL = Milligrams per deciliter, % = Percentage.

Table 2 presents comparisons of clinical and neuropathic characteristics between the male and the female participants. The mean electrochemical skin conductance (ESC) for the female participants was 56.71 (SD = 11.74); whereas, for the male participants, it was lower at 47.50 (SD = 15.00). The Neuropathy Symptom Score (NSS) was 5.37 (SD = 3.41) in the females and 7.00 (SD = 3.84) in the males.

The mean Short-form McGill Pain Questionnaire (SF-MPQ) score was 4.66 (SD = 3.70) for the females and 5.00 (SD = 4.14) for males. Foot Pain Manikin (Manikin) was higher in the males, with a mean of 17.83 (SD = 15.93), compared to 9.71 (SD = 8.35) in females. Finally, performance on the 10 g monofilament test indicated that the female participants detected an average of 3.21 (SD = 3.82) points, while the male participants detected fewer, with a mean of 2.00 (SD = 3.34).

Table 2. Demographic Characteristics of Sudoscan Parameters and Neuropathic Symptoms Mean Scores.

Characteristics	DPN (N = 44)	Female (N = 38)	Male (N = 6)
ESC M ± SD	55.45 ± 12.45	56.71 ± 11.74	47.50 ± 15.00
NSS M ± SD	5.59 ± 3.47	5.37 ± 3.41	7.00 ± 3.84
SF-MPQ M ± SD	4.70 ± 3.71	4.66 ± 3.70	5.00 ± 4.14
Manikin M ± SD	10.82 ± 9.77	9.71 ± 8.35	17.83 ± 15.93
10 g M ± SD	3.04 ± 3.74	3.21 ± 3.82	2.00 ± 3.34

Abbreviations: **ESC** = Electrochemical Skin Conductance, **NSS** = Neuropathy Symptom Score, **Manikin** = Foot Pain Manikin, **SF-MPQ** = Short-form McGill Pain Questionnaire. **10 g** = 10 g Monofilament Test.

Correlation between Sudoscan Parameters and Neuropathic Symptoms

The electrochemical skin conductance (ESC) showed significant negative correlations with the neuropathic symptom measures (Table 3). The Pearson's correlation coefficient between ESC and the Neuropathy Symptom Score (NSS) was $r = -0.583$, $P < 0.001$, indicating a moderate to strong inverse relationship. Similarly, ESC was negatively correlated with Short-form McGill Pain Questionnaire (SF-MPQ) scores ($r = -0.401$, $P = 0.007$) and Foot Pain Manikin (Manikin) values ($r = -0.411$, $P = 0.006$). Additionally, a significant negative correlation was observed between ESC and the 10 g monofilament test ($r = -0.394$, $P = 0.008$).

Table 3. Pearson's Correlation between Electrochemical Skin Conductance and Neuropathic Symptom Scores.

	Correlation Coefficient	Sig (2 tailed)	N
NSS	-0.583	<0.001	44
SF-MPQ	-0.401	0.007	44
Manikin	-0.411	0.006	44
10 g	-0.394	0.008	44

Abbreviations: **ESC** = Electrochemical Skin Conductance, **NSS** = Neuropathy Symptom Score, **Manikin** = Foot Pain Manikin, **SF-MPQ** = Short-form McGill Pain Questionnaire. **10 g** = 10 g Monofilament Test.

DISCUSSION

Sudoscan as a Diagnostic Tool for Diabetic Peripheral Neuropathy

Our findings support the clinical utility of Sudoscan in assessing neuropathic dysfunction in individuals with diabetic peripheral neuropathy (DPN). The significant negative correlations between electrochemical skin conductance (ESC) and neuropathic symptom measures, including the Neuropathy Symptom Score (NSS), Short-form McGill Pain Questionnaire (SF-MPQ), and Foot Pain Manikin (Manikin) indicate that Sudoscan provides valuable insight into the severity of small fiber neuropathy (SFN). This aligns with previous research suggesting that reduced ESC values are associated with worsening neuropathic symptoms and may serve as an early indicator of autonomic dysfunction in diabetes (8,17).

Comparison with Traditional Neuropathy Assessments

The results further emphasize the limitations of conventional neuropathy assessment tools, such as the 10 g monofilament test that primarily evaluates large fiber function. In this study, the 10 g monofilament test results were also significantly correlated with ESC, reinforcing the notion that Sudoscan captures a broader spectrum of neuropathic impairment. These findings are consistent with prior studies demonstrating that small fiber dysfunction precedes large fiber impairment in diabetic neuropathy. This aligns with findings from Breiner et al., which indicate that small-fiber dysfunction occurs early in diabetic sensorimotor polyneuropathy (DSP) in type 1 diabetes (1). Furthermore, ESC has been shown to serve as a sensitive marker for detecting early-stage neuropathy (3). Given that traditional methods such as nerve conduction studies are invasive and require specialized equipment, Sudoscan presents a non-invasive, rapid, and objective alternative for neuropathy screening in clinical practice.

Sex Differences in Neuropathic Symptoms

An interesting observation in this study was the sex-related differences in neuropathic measures. Although the female participants exhibited higher ESC values, they reported comparable levels of pain and neuropathic symptoms to the male participants, who had significantly lower ESC values. Moreover, the males demonstrated higher Manikin scores, suggesting a greater distribution of foot pain. These findings are in line with existing literature indicating that sex differences in pain perception and nerve function may be influenced by hormonal factors and pain modulation pathways (12,13). Future studies should investigate the underlying mechanisms contributing to these differences to improve individualized treatment strategies.

Clinical Implications and Future Directions

The strong inverse correlation between ESC and neuropathic symptom severity underscores Sudoscan's potential as a clinical tool for DPN screening and monitoring. Given that it detects early dysfunction, Sudoscan could aid in stratifying patients based on neuropathy risk and guiding timely interventions. Longitudinal studies are needed to assess whether changes in ESC over time reflect neuropathy progression and treatment efficacy. Additionally, integrating Sudoscan with other diagnostic modalities, such as quantitative sensory testing (QST) may enhance its diagnostic accuracy (9).

Limitations in this Study

While this study provides valuable insights, several limitations should be acknowledged. The sample size was relatively small, particularly for the male participants that may have influenced the generalizability of our sex-based findings. Additionally, this study was cross-sectional, therefore, causal relationships between ESC and neuropathic progression cannot be inferred. Future research should incorporate larger, more diverse populations, and longitudinal designs to validate our findings and establish ESC as a prognostic biomarker for DPN.

CONCLUSIONS

This study demonstrates the utility of Sudoscan in assessing neuropathic dysfunction in patients with diabetic peripheral neuropathy (DPN). The significant correlations between electrochemical skin conductance (ESC) and neuropathic symptom measures indicate that ESC effectively reflects both small and large fiber impairment. These findings highlight Sudoscan as a promising non-invasive tool for evaluating neuropathy severity.

From an exercise physiology perspective, the integration of Sudoscan in clinical and rehabilitation settings may provide valuable insights into neuromuscular function, aiding in the development of exercise interventions tailored to individuals with DPN. Early detection of neuropathic impairments through ESC assessment could facilitate targeted exercise prescriptions to enhance peripheral circulation, neuromuscular control, and overall functional mobility.

Future research should investigate the longitudinal changes in ESC with structured exercise interventions and explore its predictive value in monitoring neuropathy progression and treatment efficacy. Standardizing ESC reference values across diverse populations will further strengthen its clinical applicability.

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Effect of Soybean Milk in Conjunction with Aerobic Exercise on VO_2Max and Body Composition of College Students

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ABSTRACT

Su Fei, Thanaphonganan N. Effect of Soybean Milk in Conjunction with Aerobic Exercise on VO_2Max and Body Composition of College Students. The purpose of this study was to examine the effects of soybean milk combined with aerobic exercise on VO_2Max and body composition in male college students aged 18 to 21. Thirty participants were assessed for VO_2Max using the Harvard Step Test and body composition via bioelectrical impedance analysis. They were stratified by VO_2Max and randomly assigned to 3 Groups (n = 10): (1) Soybean Milk + Exercise (500 mL soybean milk with 4 g stevia); (2) Placebo + Exercise (stevia-sweetened water); and (3) Exercise Only. All Groups completed an 8-week aerobic training program (3 sessions per week). Results showed that the Soybean Milk Group significantly increased skeletal muscle mass, total muscle mass, and body protein ($P < .001$), with larger gains than the other Groups ($P < .05$). The Placebo Group showed significant weight reduction ($P = .007$), while the Exercise-Only Group saw reductions in weight, BMI, and body fat percentage ($P < .05$). No significant changes in VO_2Max were found in any of the 3 Group. In conclusion, soybean milk supplementation improved muscle-related body composition during aerobic training, but it had no significant effect on VO_2Max.

Key Words: Aerobic Exercise, Nutritional Supplementation, Soybean Milk, VO_2Max

INTRODUCTION

In recent years, lifestyle-related health issues such as obesity, sedentary behavior, and poor nutritional choices have become increasingly prevalent among college students, particularly among the young males. Despite being in a critical life stage for establishing lifelong health habits, this population often demonstrates suboptimal levels of physical activity and imbalanced dietary patterns. Regular aerobic exercise has been widely acknowledged as a cornerstone of health promotion, known to improve cardiovascular fitness, regulate body weight, reduce fat mass, and enhance psychological well-being (7,15,22). However, the outcomes of the exercise interventions alone may vary significantly depending on individual factors, such as training intensity, adherence, and nutritional status (6).

In this context, nutritional strategies have gained increasing attention for their potential to augment training adaptations. One area of growing interest is the role of plant-based proteins, especially soy protein as a dietary intervention. Soybean milk, a plant-based beverage rich in high-quality protein, essential amino acids (notably leucine), unsaturated fats, and bioactive compounds, such as isoflavones has been shown to stimulate muscle protein synthesis via the mTOR pathway and promote anabolic responses following exercise (11,14,17). Compared to dairy proteins, soy offers additional advantages that include being cholesterol-free and suitable for individuals with lactose intolerance or following vegetarian or flexitarian diets (19).

Majority of the existing literature on soy protein supplementation has focused on resistance training or clinical populations, such as older adults or individuals with sarcopenia (1,3,5). These studies consistently report improvements in muscle mass, strength, and body composition. However, evidence on the interaction between soy supplementation and aerobic training remains sparse and inconclusive. While some trials suggest marginal improvements in muscle maintenance or body fat reduction, others find little to no added benefit on aerobic performance as indicated by maximal oxygen uptake (VO_2Max) (9,16).

VO_2Max is a key marker of cardiorespiratory fitness and aerobic performance capacity. It is often used to predict endurance potential and cardiovascular health. Enhancing VO_2Max typically requires sustained, progressive overload through moderate-to-high-intensity training. Whether soy supplementation can amplify VO_2Max, particularly in healthy young males who engage in moderate aerobic routines remains unclear. Moreover, methodological issues, such as the use of indirect VO_2Max estimation methods like the Harvard Step Test may further obscure potential effects (10).

Given this background, the purpose of this study was to investigate the effect of soybean milk supplementation in combination with aerobic exercise on VO_2Max and body composition among male college students. We hypothesize that pre-exercise soy supplementation will lead to greater improvements in skeletal muscle mass, total lean mass, and estimated body protein compared to aerobic exercise alone or exercise with placebo. We are also interested in whether this strategy influences VO_2Max and post-exercise heart rate recovery. The results may show new insights into integrated approaches to fitness and nutrition for the young adult population and inform health promotion policies aligned with global initiatives, such as the WHO's Global Action Plan on Physical Activity 2018-2030 and the Healthy China 2030 Plan.

METHODS

Participants

This study employed a randomized controlled trial design. A total of 51 male undergraduate students majoring in fitness guidance and management were initially screened for eligibility. Thirty participants met the inclusion criteria. They were randomly selected to take part in this study. All the participants provided written informed consent prior to enrollment. The study received ethical approval from the Institutional Ethics Committee, and it was conducted in accordance with the Declaration of Helsinki.

Group Allocation

The participants were randomly assigned to 1 of 3 Groups (n = 10 per Group) using stratified randomization based on baseline VO_2Max values, assessed via the Harvard Step Test, to ensure comparable levels of cardiorespiratory fitness across the Groups. Allocation was conducted using a computer-generated randomization sequence by an independent researcher who was not involved in data collection.

The 3 Groups consisted of the **Soybean Milk + Exercise Group** (SM + EX; n = 10) of which the participants consumed 500 mL of soybean milk containing 4 g of stevia 30 minutes before each exercise session, the **Placebo + Exercise Group** (PL + EX; n = 10) that consumed 500 mL of water sweetened with 4 g of stevia, which was matched for color, taste, and volume to the soybean milk 30 minutes before each session; and the **Exercise-Only Group** (EX Only; n = 10) that performed the same exercise protocol without any supplementation. To minimize expectancy bias, the participants in the SM + EX Group and the PL + EX Group were blinded to the contents of their beverages. All the participants received standardized exercise instructions, and they were supervised throughout the intervention period.

Intervention Protocol

The intervention lasted 8 weeks, with the participants engaging in the supervised aerobic exercise sessions 3 times per week (Monday, Wednesday, and Friday) at 7:00 p.m. Each session included a 10-minute warm-up, followed by 30 minutes of treadmill running at an intensity that ranged from 65% to 80% of their maximum heart rate, and concluded with a cool-down phase.

The participants were instructed to maintain their habitual diet, abstain from alcohol, caffeine, and additional soy products for 24 hours prior to each testing session, and they were told to obtain 6 to 8 hours of sleep per night. Dietary adherence was monitored via a 3-day food diary collected at both baseline and post-intervention. Weekly sleep duration and perceived stress levels were recorded using validated self-report questionnaires.

Outcome Measures

The primary and secondary outcome measures were assessed at baseline and after the 8-week intervention under standardized laboratory conditions. Cardiorespiratory fitness was evaluated using the Harvard Step Test, with an estimated VO_2Max calculated through validated prediction equations based on step test performance. Resting heart rate and recovery heart rate (immediately and 3 minutes post-exercise) were measured using a calibrated finger pulse oximeter. Body composition was assessed using a validated multi-frequency bioelectrical impedance analyzer (Tsinghua Tong-Fang Body Composition Analyzer, Beijing, China) that provided measures of body weight, body mass index (BMI), body fat percentage, skeletal muscle mass, total muscle mass, estimated total body protein mass, and waist-to-hip ratio.

The participants also completed validated questionnaires to assess their perceptions and experiences related to the intervention, including the Questionnaire on Soybean Milk Interaction (QSMI), Health Assessment Record Form (HARF), Physical Activity Readiness Questionnaire (PARQ), and a Questionnaire on Feelings and Symptoms Interaction (QFSI). All assessments were conducted by trained evaluators following a standardized protocol to ensure consistency and minimize inter-rater variability.

Data Collection
Baseline and post-intervention data were collected under standardized laboratory conditions at the university's exercise science facility. All physiological assessments were performed by trained assessors blinded to group allocation to reduce measurement bias. The participants were instructed to abstain from vigorous exercise, alcohol, caffeine, and soy products for at least 24 hours prior to testing, and to maintain consistent hydration and sleep routines. All the measurement devices were calibrated prior to each session according to manufacturer guidelines.

The questionnaire data were collected in a quiet, private setting using validated instruments (QSMI, HARF, PARQ, and QFSI), with trained research assistants available to clarify any uncertainties. Data entry was independently performed by 2 research assistants, and discrepancies were resolved by cross-referencing the original data sheets. All the data were securely stored in a password-protected database, and the participant confidentiality was maintained throughout in accordance with institutional ethical standards.

Statistical Analyses

All statistical analyses were performed using the SPSS version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as means ± standard deviations (SD). Prior to inferential testing, the data distributions were assessed for normality using the Shapiro-Wilk Test, and homogeneity of variance was evaluated using the Levene's Test. All assumptions for parametric testing were satisfied.

Within-group differences between pre- and post-intervention measurements were assessed using paired-sample *t*-tests. Between-group differences at post-intervention were evaluated using one-way analysis of variance (ANOVA), followed by Bonferroni-adjusted *post hoc* tests to control for family-wise error due to multiple comparisons. For each the inferential test, test statistics, degrees of freedom (df), exact P-values, and effect sizes were reported. Cohen's d was calculated for paired *t*-tests to indicate within-group effect sizes, while partial eta-squared (η^2) was computed for ANOVA to indicate between-group effect sizes. The effect sizes were interpreted according to conventional thresholds (small: $d \geq 0.20$, medium: $d \geq 0.50$, large: $d \geq 0.80$). Confidence intervals (95% CI) for effect sizes were also computed.

All the tests were two-tailed with an alpha level set at 0.05. The analysis was conducted using a complete-case approach, given that no participants were lost to follow-up. Thus, the complete-case analysis was equivalent to intention-to-treat in this trial.

RESULTS

Participant Characteristics

All 30 participants completed the 8-week intervention, and no adverse events were reported. The participants were randomly assigned to 3 Groups with equal allocation (n = 10 per Group). Baseline demographic and anthropometric characteristics were comparable across the Groups, with no statistically significant differences in age, height, or body weight (refer to Table 1).

Table 1. The Baseline Characteristics of the Participants.

Variable	SM + EX (n = 10)	PL + EX (n = 10)	EX Only (n = 10)	F (df = 2,27)	P
Age (y)	19.7 ± 0.8	19.8 ± 0.8	19.6 ± 0.8	0.14	.872
Height (cm)	176.1 ± 2.7	174.4 ± 2.9	173.4 ± 2.7	1.45	.251
Weight (kg)	72.6 ± 6.1	72.2 ± 5.4	70.4 ± 4.7	0.89	.423

Note: The values are presented as mean ± standard deviation. **SM + EX** = Soybean Milk plus Exercise; **PL + EX** = Placebo plus Exercise; **EX Only** = Exercise Only; **y** = Years; **cm** = Centimeters; **kg** = Kilograms. **P**-values were obtained from one-way ANOVA comparing baseline characteristics.

The results presented in Table 1 indicate that there were no statistically significant differences in the baseline characteristics among the 3 Groups. Age, height, and body weight were well balanced across the SM + EX, PL + EX, and EX Only Groups, as confirmed by one-way ANOVA ($P > 0.05$ for all comparisons). These statistical findings indicate that the randomization process was successful in producing comparable Groups prior to the intervention, thus reducing the risk of baseline confounding in subsequent outcome analyses. The homogeneity of these characteristics supports the internal validity of the study and allows for a fair comparison of the intervention effects among the 3 Groups.

Body Composition

Following the 8-week intervention, significant within-group changes were observed in body composition across the 3 Groups. In the **Soybean Milk plus Exercise Group** (SM + EX), skeletal muscle mass increased significantly from 35.96 ± 3.06 kg at baseline to 38.10 ± 2.66 kg post-intervention, $t(9) = 5.43$, $P < .001$, Cohen's $d = 1.04$, 95% CI [0.27, 1.80]. Also, total muscle mass increased from 56.20 ± 4.79 kg to 59.50 ± 4.13 kg, $t(9) = 6.02$, $P < .001$, $d = 1.43$, 95% CI [0.56, 2.29]. Furthermore, estimated total body protein mass rose from 12.35 ± 1.05 kg to 13.16 ± 0.91 kg, $t(9) = 6.22$, $P < .001$, $d = 1.54$, 95% CI [0.65, 2.43]. These changes reflect large effect sizes across all the muscular indices. In the **Placebo plus Exercise Group** (PL + EX), a significant reduction in body weight was observed with a decrease from 72.22 ± 5.41 kg to 70.98 ± 5.29 kg, $t(9) = 3.32$, $P = .007$, $d = 0.71$, 95% CI [0.10, 1.30]. In the **Exercise-Only Group** (EX Only), significant decreases were found in body weight (70.42 ± 4.69 kg to 67.82 ± 3.36 kg), $t(9) = 3.06$, $P = .017$, $d = 0.66$, 95% CI [0.06, 1.23]; BMI (23.16 ± 1.73 kg/m² to 22.69 ± 1.43 kg/m²), $t(9) = 3.07$, $P = .012$, $d = 0.66$, 95% CI [0.06, 1.23]; and body fat percentage (16.82 ± 3.27% to 15.58 ± 3.04%), $t(9) = 3.12$, P = .010, *d* = 0.67, 95% CI [0.07, 1.25]. There were no significant within-group changes in estimated VO_2Max in any of the Groups (P > .05).

Table 2. The Within-Group Comparisons of Body Composition and Fitness Outcomes (Pre- vs. Post-Intervention).

Variable	Group	Pre (Mean ± SD)	Post (Mean ± SD)	*t*(df)	P	Cohen's d (95% CI)
Skeletal Muscle (kg)	SM + EX	35.96 ± 3.06	38.10 ± 2.66	5.43 (9)	< .001	1.04 (0.27, 1.80)
Muscle Mass (kg)	SM + EX	56.20 ± 4.79	59.50 ± 4.13	6.02 (9)	< .001	1.43 (0.56, 2.29)
Protein Mass (kg)	SM + EX	12.35 ± 1.05	13.16 ± 0.91	6.22 (9)	< .001	1.54 (0.65, 2.43)
Weight (kg)	PL + EX	72.22 ± 5.41	70.98 ± 5.29	3.32 (9)	.007	0.71 (0.10, 1.30)
Weight (kg)	EX Only	70.42 ± 4.69	67.82 ± 3.36	3.06 (9)	.017	0.66 (0.06, 1.23)
BMI (kg/m^2)	EX Only	23.16 ± 1.73	22.69 ± 1.43	3.07 (9)	.012	0.66 (0.06, 1.23)
Body Fat (%)	EX Only	16.82 ± 3.27	15.58 ± 3.04	3.12 (9)	.010	0.67 (0.07, 1.25)

Note: **SM+EX** = Soybean Milk plus Exercise; **PL+EX** = Placebo plus Exercise; **EX Only** = Exercise Only; **BMI** = Body Mass Index; **VO_2Max** = Maximal Oxygen Uptake; **SD** = Standard Deviation; **CI** = Confidence Interval.

As shown in Table 2, the participants in the SM+EX Group experienced the most substantial within-group improvements in muscle-related body composition outcomes, including significant increases in skeletal muscle mass, total muscle mass, and estimated protein mass, all with large effect sizes. In contrast, both the PL+EX Group and the EX Only Group demonstrated significant reductions in body weight, BMI, and body fat percentage without a corresponding increase in the lean muscle mass parameters. The absence of significant within-group changes in estimated VO_2Max across all the Groups suggests that the intervention may have been insufficient in duration or intensity to produce measurable improvements in cardiorespiratory fitness.

Cardiorespiratory Fitness and Heart Rate Outcomes

The estimated VO_2Max was calculated via the Harvard Step Test prediction equations. No statistically significant within-group changes in estimated VO_2Max were observed in any of the 3 Groups (P > .05). Similarly, there were no significant within-group or between-group differences in heart rate measured immediately post-exercise or at 3 minutes post-exercise.

Between-Group Comparisons

The one-way ANOVA revealed statistically significant between-group differences at post-intervention for skeletal muscle mass, $F(2, 27) = 6.09$, P = .005, $\eta^2 = .31$; total muscle mass,

$F(2, 27) = 6.23$, P = .006, $\eta^2 = .32$; and estimated protein mass, $F(2, 27) = 7.59$, P = .003, $\eta^2 = .36$. The Bonferroni *post hoc* analyses indicated that the SM+EX Group achieved significantly greater improvements in these outcomes compared to both the PL+EX Group and the EX Only Group (P < .05). No significant between-group differences were observed for body weight, BMI, body fat percentage, or estimated VO_2Max (P > .05 for all comparisons).

Table 3. Between-Group Comparisons After 8 Weeks.

Variable	SM+EX (Mean ± SD)	PL+EX (Mean ± SD)	EX Only (Mean ± SD)	F (df = 2,27)	P	η^2 (Partial Eta Squared)	Significant Comparisons (Bonferroni)
Skeletal Muscle (kg)	38.10 ± 2.66	35.39 ± 2.26	34.58 ± 1.76	6.09	.005	.31	SM+EX > PL+EX, EX Only
Total Muscle Mass (kg)	59.50 ± 4.13	55.42 ± 3.60	54.04 ± 2.76	6.23	.006	.32	SM+EX > PL+EX, EX Only
Protein Mass (kg)	13.16 ± 0.91	12.17 ± 0.77	11.90 ± 0.60	7.59	.003	.36	SM+EX > PL+EX, EX Only
Body Weight (kg)	71.22 ± 5.11	70.98 ± 5.29	67.82 ± 3.36	2.11	.140	.13	n.s.
BMI (kg/m^2)	22.79 ± 1.51	22.94 ± 1.60	22.69 ± 1.43	0.07	.932	.01	n.s.
Body Fat (%)	16.00 ± 2.95	15.68 ± 3.01	15.58 ± 3.04	0.10	.906	.01	n.s.
VO_2Max (mL/kg/min)	(estimated)	No significant difference across groups		0.92	.411	.06	n.s.

Note: SM+EX = Soybean Milk plus Exercise; **PL+EX** = Placebo plus Exercise; **EX Only** = Exercise Only; **η^2** = Partial eta Squared; n.s. = Not Significant.

Heart Rate Comparisons

As shown in Table 4, no significant between-group differences were observed in heart rate measurements either immediately after exercise ($F(2,27) = 0.75$, P = .485, $\eta^2 = .05$) or at three minutes post-exercise ($F(2,27) = 1.66$, $P = .204$, $\eta^2 = .11$). These findings underscore the additive effect of soybean milk supplementation in enhancing muscle-related adaptations when combined with aerobic training, while suggesting no measurable impact on acute heart rate recovery responses.

Table 4. Heart Rate Comparisons After 8 Weeks.

Time Point	SM + EX (Mean ± SD)	PL + EX (Mean ± SD)	EX Only (Mean ± SD)	F (df = 2,27)	P	η^2
Immediately After Exercise	138.4 ± 9.7	135.1 ± 13.4	126.8 ± 9.2	0.75	.485	.05
3 Min After Exercise	106.0 ± 8.3	105.2 ± 7.3	99.1 ± 4.8	1.66	.204	.11

Note: SM+EX = Soybean Milk plus Exercise; **PL+EX** = Placebo plus Exercise; **EX Only** = Exercise Only; **η^2** = Partial eta Squared.

DISCUSSION

The purpose of this randomized controlled trial was to evaluate the impact of soybean milk supplementation combined with aerobic exercise on body composition and cardiorespiratory fitness in male college students. The most salient finding was that the Group that received soybean milk before the exercise sessions (the SM + EX) experienced significantly greater improvements in skeletal muscle mass, total muscle mass, and estimated total body protein mass compared to the placebo (PL + EX) and exercise-only (the EX Only) Groups.

These outcomes align with previous studies showing that soy protein supplementation can enhance muscular adaptations by promoting muscle protein synthesis via the mTOR signaling pathway, particularly when consumed around periods of physical activity (14,17). More recently, Kritikos et al. (14) and Stoodley et al. (19) reported that soy-based protein can elicit comparable effects to whey protein in increasing lean body mass and functional strength, especially when paired with endurance or concurrent training in young adults.

Although soy protein is often studied in the context of resistance training, our findings suggest that even moderate-intensity aerobic exercise can synergize with high-quality plant protein intake to promote favorable changes in lean tissue metrics. Zare et al. (23) found similar results among female runners supplemented with soy protein, showing an increase in fat-free mass without strength training. Conversely, Bosland et al. (5) reported no significant effects of soy supplementation on muscle mass in sedentary older adults, suggesting that exercise is a critical mediator of response.

Interestingly, despite these improvements in muscle-related parameters, there were no significant changes in estimated VO_2Max or heart rate recovery across any of the 3 Groups. One likely explanation is the relatively short duration (8 weeks) and moderate intensity of the aerobic training protocol that may have been insufficient to elicit significant cardiorespiratory adaptations, especially when measured indirectly via the Harvard Step Test. Previous research has shown that VO_2Max is sensitive to both the duration and intensity of exercise, with more robust changes observed in longer-term or high-intensity programs (9,21). Bouchard & Rankinen (6) also emphasized that significant increases in VO_2Max generally required exercise intensities near or above the anaerobic threshold.

The null findings in VO_2Max also underscore the limitations of using field-based prediction equations. Although the Harvard Step Test is practical and accessible, its lower sensitivity compared to direct gas exchange methods could have obscured subtle improvements in aerobic capacity (2). In support of this, Ho et al. (10) demonstrated that VO_2Max estimates from the Step Test can underreport actual improvements, particularly in trained populations.

This study has several strengths, including its randomized controlled design, blinding of participants to beverage content, and the use of validated measurement tools. However, limitations should also be acknowledged. The sample size was modest, and the participants were limited to a single demographic group (young male students), limiting generalizability. Furthermore, dietary intake outside the study was only loosely controlled, and reliance on BIA for body composition, while practical, lacks the precision of dual-energy X-ray absorptiometry (DEXA).

Future research should consider extending the duration of the intervention, incorporating both genders, and using more sensitive measurement tools for VO_2Max and lean mass. Additionally, it would be beneficial to investigate whether combining soybean milk with resistance or high-intensity interval training could yield even greater benefits in both muscular and cardiovascular adaptations (16).

In summary, soybean milk supplementation in conjunction with aerobic exercise significantly improved muscle-related body composition metrics, including skeletal muscle mass and total body protein mass. However, the supplementation had no measurable effect on cardiorespiratory fitness within the study's timeframe. These findings support the integration of plant-based protein strategies into aerobic training regimens for muscle development in young adults.

Limitations in this Study

One notable limitation lies in the method used to estimate VO_2Max. The Harvard Step Test is an indirect field-based method with known limitations in accuracy, particularly when compared to the gold-standard assessment that uses direct gas exchange analysis. While convenient and practical in a university setting, this test may not capture subtle changes in cardiorespiratory capacity and may introduce individual variability. This limitation reduces the confidence with which conclusions about aerobic capacity can be drawn.

Additionally, it is unclear whether key statistical assumptions were systematically verified prior to conducting inferential analyses. Future research should explicitly assess and report assumptions of normality and homogeneity of variance when using parametric tests such as t-tests and ANOVA, as violations of these assumptions may affect the validity of the results. Some important statistical values were not fully reported in the current manuscript. For example, F-values and degrees of freedom (df) for ANOVA, as well as exact P-values for *post hoc* comparisons, were not consistently presented. This incomplete reporting may hinder readers' ability to independently assess the robustness of the findings. Future reporting should follow established guidelines such as the CONSORT and APA reporting standards for transparency and reproducibility.

Also, this study was not registered in a clinical trial registry such as ClinicalTrials.gov. Although registration is not mandatory for small-scale pilot studies, prospective registration of randomized controlled trials is increasingly considered the best practice in research ethics and transparency. Future investigations should consider trial registration to enhance methodological rigor and reporting clarity.

CONCLUSIONS

This randomized controlled trial examined the effects of soybean milk supplementation combined with aerobic exercise on estimated VO_2Max and body composition in male college students. The results demonstrated that while aerobic training alone led to reductions in weight and fat mass across all groups, only the Group that received soybean milk exhibited significant gains in skeletal muscle mass, total muscle mass, and estimated total body protein mass. These findings suggest that soybean milk, as a plant-based protein source, can effectively enhance muscular adaptations when incorporated into aerobic training regimens.

However, no statistically significant improvement was observed in cardiorespiratory fitness, which was likely due to the moderate intensity and limited duration of the intervention, as well as the use of indirect estimation methods. This underscores the importance of aligning exercise prescriptions with appropriate nutritional strategies to maximize the physiological benefits. Future research should extend the duration of interventions, include more diverse populations (e.g., both genders and varied age groups), and assess whether combining soy supplementation with resistance or high-intensity interval training yields improvements in both muscular and cardiovascular fitness domains. Such work would contribute to evidence-based strategies for integrating plant-based nutrition into exercise programs for health promotion in young adults.

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The Effects of Pound® Exercise Moderate-Load for Maximal Oxygen Uptake, Body Composition, and Satisfaction in Overweight Youths

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ABSTRACT

Wanna S, Phannikul T, Wongsason P, Sitthang C, Luengphetngam W. The Effects of Pound® Exercise Moderate-Load for Maximal Oxygen Uptake, Body Composition, and Satisfaction in Overweight Youths. Participants were divided into 2 Groups, the Experimental Group that underwent Pound® drumstick training and the Control Group that maintained a normal daily routine. The Experimental Group trained 3 times per week, 30 minutes per session, over a period of 6 weeks. Statistical analysis revealed significant differences at the .05 level between the pre- and post-training measurements in the Experimental Group. Specifically, there were increases in VO_2 Max and muscle mass, and decreases in body weight, fat mass, and body fat percentage. Post-training comparisons between the Experimental Group and the Control Group showed that the Experimental Group had significantly lower average fat mass and body fat percentage, along with a higher oxygen consumption rate. The participant satisfaction with the training program was rated at the highest level, with an average score of 4.77. The findings indicate that Pound® training can be effectively incorporated into fat-reduction programs for overweight individuals. A minimum duration of 6 weeks is recommended. The program offers a dynamic and enjoyable approach to exercising and promoting both fat loss and improved cardiovascular fitness.

Key Words: Drumming, Exercise Intensity, POUND Exercise Moderate-Load Overweight

INTRODUCTION

Adolescents spend a large amount of time on social media every day, which increases their risk of becoming overweight or obese. This is often due to their reduced physical activity, poor eating habits, and insufficient sleep. These factors contribute to excessive weight gain that can lead to various health problems, including diabetes, heart disease, and high blood pressure. Obese people and those with non-communicable diseases (NCDs) are at a higher risk of experiencing severe illness and death compared to those with normal health. Studies have shown that people with a body mass index (BMI) greater than 30 kg/m^2 are 74% more likely to experience severe illness and require intensive care unit (ICU) admission than those with normal weight (14).

Additionally, excessive body fat contributes to increased inflammation, insulin resistance, high blood sugar levels, and weak immune function. These factors increase the severity of illness, and the risk of death compared to people with a healthy body weight. Overweight people are also at risk, although to a lesser extent than those who are obese. It is not only elderly people who face these risks, but also adolescents who are overweight or obese with an increased risk of death. Therefore, regular exercise is crucial in reducing the severity of different diseases and lowering mortality rates (23).

Pound®, a drumstick exercise, is a physiologically and neurologically based workout that incorporates a unique and complex technique for group exercise. It must be led by the instructors certified with Pound pro. It was created by Kirsten Potenza in 2018 who was inspired by the rhythmic beat of drums. It offers a fun and relaxing workout that can burn calories. In 2018, Thailand introduced the Pound® class to fitness gyms, led by qualified fitness instructors who completed the Pound pro training program. Pound® combines cardio with energetic music. The exercise moves are based on Yoga and Pilates, and Ripstix®. Lightweight, flexible, and durable drumsticks are used in that they are specifically designed for this type of exercise, which engages all parts of the body in a coordinated effort. It is similar to drumming that also requires coordinated movement of various body parts, such as the hands holding the drumsticks and the legs driving the movement, which stimulates the nervous system and muscles that are used.

A study among people with split-brain syndrome, a condition where the corpus callosum (the nerve fibers connecting the left and right hemispheres of the brain) is partially or completely severed, caused by the disruption of communication between the hemispheres, revealed that training involving bimanual movements has been shown to improve movements and body control (12). Based on the body movements involved in drumming mentioned above, it can be concluded that drumming requires coordinated use of both hands and feet, engaging both sides of the brain and nervous system. This coordination enhances brain function, promotes body balance, and improves movement control and responsiveness to the environment.

Pound® is designed to begin with basic exercises and is progressively increased in intensity as the body adapts and gains strength. It combines Pilates and Yoga. Pilates is an alternative form of exercise that promotes both physical and mental health and healing (9,10,32,37). Pilates was developed in 1880 as a form of exercise that primarily focused on strengthening the core muscles (31). In addition, it incorporates simple and easy-to-follow movement patterns based on 6 fundamental principles: centering, concentration, control, precision, breath, and flow (19). These principles make Pilates a fun, safe, and effective workout that offers an alternative method to reduce body fat and improve body composition, especially for overweight or obese people (2,8). Yoga is a popular form of exercise that has been practiced from the past until the present. It is one of the oldest branches of Indian science and is known for its focus on enhancing physical strength, flexibility, and mental well-being. Yoga is suitable for people of all ages. Yoga practice helps to strengthen muscles, improve body movement, and increase flexibility and elasticity. It also reduces muscle tension, stabilizes the mind, enhances concentration, and alleviates stress. In recent years, yoga has been incorporated into various types of exercises, including Pound®.

Additionally, Pound® involves continuous and complex movements promote muscle and nervous system adaptations and muscle efficiency that improves the nervous system's ability to coordinate body movements. As a result, it helps to maintain balanced serotonin levels, that lead to an improvement in emotional stability and a decrease in the risk of depression. Furthermore, Pound® increases norepinephrine levels, which plays a key role in regulating emotions and enhancing concentration. The continuous movement in this exercise helps to improve the length and range of motion of the tendons, joints, and muscle fibers. It incorporates both dynamic stretching and static stretching that helps to prevent muscle strains, reduces the risk of injury, and contributes to the increase in muscle strength and cardiovascular endurance. Pound® enhances both physical and mental health, increases immunity, and helps to decrease the risk of hospitalization, severe illness, and mortality from infectious diseases (18). However, many of the mechanisms behind these positive outcomes are still unclear. Research studies worldwide have not yet provided sufficient data to draw a clear conclusion. Also, the effects of Pound® remain inconclusive.

Therefore, the purpose this study was to explore methods for improving physical fitness, maximal oxygen uptake, body composition, and overall satisfaction in overweight youths. This research provided volunteers with a moderate-intensity drumstick exercise (Pound®), which may contribute to new knowledge and have potential applications for patients with both communicable and non-communicable diseases in the future. The purpose is to explore innovative prevention and treatment methods that could decrease or replace the need for medication. The knowledge gained from this study can be applied both academically and practically, providing methods and guidelines for the prevention and treatment of diseases associated with the risk factors of overweight, which can lead to improved quality of life. This is the primary goal of this study.

METHODS

This research employed a mixed-methods approach, combining quantitative and qualitative research methods, using experimental research and the use of questionnaires.

Subjects

The samples consisted of 40 students aged 19 to 24 years who were overweight (BMI of 23.0 to 24.9 kg/m^2). They voluntarily agreed to participate in this study. The sample size was determined using power analysis, with the G*Power 3.1.9.4 program. The effect size was set at 0.87, which was based on the findings of a study by Rayes et al. (25). The statistical significance level was set at 0.05, and the power of test was set at the acceptable standard of 80%. Based on the calculation, the required sample size was 36 participants. To prevent the anticipated dropout, an additional 10% was added to the calculated sample size. Therefore, the final sample size was 40 participants, divided into 2 Groups, the Experimental Group (20 participants) that received a moderate-intensity Pound® drumstick training (%MHR = 60-70%), and the Control Group (20 participants) that maintained a normal daily routine. The study was approved by the Ubon Ratchathani Rajabhat University Ethics Committee for Human Research (Reference Number: HE652045).

Procedures

The ***Inclusion Criteria*** consisted of the following. The students were aged 19 to 24 years with a BMI of 23.0 to 24.9 kg/m², which meant that they were classified as overweight but in good health and not using anabolic steroids, creatine, or sympathoadrenal drugs during the study period. Also, they could not have participated in drumstick training, weight training, or aerobic exercise within 3 months prior to or during the study. The ***Exclusion Criteria*** indicated that the students could not have a history of heart disease, diabetes, high blood pressure, and cancer, a history of respiratory diseases, such as chronic lung disease, asthma, and allergies, a history of bone surgery or fractures within 3 months prior to participation in the study, or any medical symptoms that may worsen during exercise, such as dizziness, vertigo, chest pain, or tightness, underlying musculoskeletal, joint, or neurological conditions that may affect exercise performance, not currently using weight loss medications, protein supplements, or steroids, not being pregnant, or has a medical condition that may interfere with participation in the exercise program, or has a mental health or neurological problem.

The Research Process

The following exercise postures were demonstrated by the instructor for a duration of 30 minutes. The subjects in the Experimental Group began their exercise session using moderate-intensity drumsticks (Ripstix®) exercises. The exercise postures were based on the 4 basic postures Pound®: (a) **SET:** Stand with the feet wide apart, bend the knees slightly, ensuring they are aligned with the toes. Shift the weight onto the feet while keeping the back straight; (b) **LUNGE:** Stand with one leg extended behind, and gently push the chest forward. Shift the weight onto the front foot, while keeping the knees aligned with the toes; (c) **KIT:** Sit with the back straight and the torso slightly tilted back. Keep the shoulders relaxed and engage the abdominal muscles; and **T & A:** Lie on the back with the knees bent and feet hip-width apart. Lift the body, engage the abdominal muscles, and shift the weight onto the heels. Each workout consisted of 8 sets of exercises, accompanied by music. The subjects followed along to a pre-recorded, DVD based Pound® workout (24), which was obtained from the official Pound® website. The session included a 5-minute dynamic warm up, 28 minutes of Pound® movements, and a 5-minute cool-down. It was performed 3 times a week for 6 weeks. The exercise could be terminated when the subjects wanted to stop exercising or exhibited symptoms, such as dizziness, headache, nausea, or vomiting. After the experiment, both Groups were assessed for various values within 1 to 3 days following completion of the 6-weeks of training, using the same measures as before the study got underway. Moreover, the satisfaction on POUND® was evaluated using the satisfaction assessment form. The Control Group continued to carry out their normal daily routines.

Research Instruments

The data were collected by measuring body composition using a body composition monitor (seca mBCA, Germany), assessing VO_2 Max using an aerobic exercise bike (Monark 828E, Sweden), and recording the heart rate at rest and during exercise using a chest strap (Polar

H10). In addition, satisfaction among overweight youths was assessed using a satisfaction assessment form.

Statistical Analyses

The research study employed a cross-sectional research design and utilized both descriptive and inferential statistics for data analysis to address the research objectives and to test the research hypotheses. The statistics used in the data analysis included: (a) descriptive statistics to present the data with means and standard deviations; (b) inferential statistics to test the research hypotheses. All variables were presented as mean ± standard deviation and medians. The means of the variables were compared before and after the experiment within the Group and between Groups using the paired *t*-test; and (c) pre-test and post-test were conducted, with statistical significance set at 0.05.

RESULTS

This research employed a mixed-methods approach, combining quantitative and qualitative research methods, using experimental research, and the use of questionnaires. The data collection was initiated by dividing it into pre-program and post-program phases over a duration of 6 weeks. A statistical comparison of the participants in the Experimental Group (n = 20) using drumsticks and the Control Group (n = 20) is presented in Table 1, while the Means and Standard Deviations for both Groups' BMI, fat percentage, and fat mass are presented in Table 2.

Table 1. Demographic Characteristics of Participants. *P < .05 Pre-Test vs. Post-Test.

	Control Group		Experimental Group	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Age	19.60 ± 0.50		19.35 ± 0.48	
Weight	61.70 ± 4.04	61.00 ± 3.93	60.85 ± 4.78	57.25 ± 4.62*
Height	159.35 ± 6.22		159.70 ± 6.29	

*P < .05 Pre-Test vs. Post-Test.

Table 2. BMI, Percent Fat, and Fat Mass for Both Groups. *P < .05 Pre-Test vs. Post-Test.

	Control Group				Experimental Group			
	Pre-Test	Post-Test	% Change	Paired *t*-test	Pre-Test	Post-Test	% Change	Paired *t*-test
Body Mass Index	23.94±0.59	23.53±0.84	-1.68	0.027*	23.64±0.59	22.31±0.48	-6.13	0.00*
Fat Percentage	33.73±2.80	34.56±2.62	2.61	0.012*	34.09±3.67	29.56±3.13	-10.32	0.00*
Fat Mass	22.42±2.05	22.90±1.70	1.32	0.214	23.77±21.87	21.87±2.25	-8.72	0.00*

Table 3. Comparison of the Pre-Test and the Post-Test VO_2 Max in the Experimental Group and the Control Group.

	Control Group				Experimental Group			
	Pre-Test	Post-Test	% Change	Paired *t*-test	Pre-Test	Post-Test	% Change	Paired *t*-test
VO_2 Max	31.06±2.70	32.06±2.52	3.69	0.116	31.30±4.73	35.49±5.09	10.70	0.004*#

*P < .05 Pre-Test vs. Post-Test. #P < .05 Experimental Group vs. Control Group.

Table 3 shows that the VO_2 Max before and after training in the Control Group and the Experimental Group differs significantly between the 2 Groups (P < .05). The Control Group's VO_2 Max before training was 31.06 ± 2.70, which increased to 32.06 ± 2.52 after training, while the Experimental Group had a VO_2 Max of 31.30 ± 4.73 before training, which increased to 35.49 ± 5.09 after training.

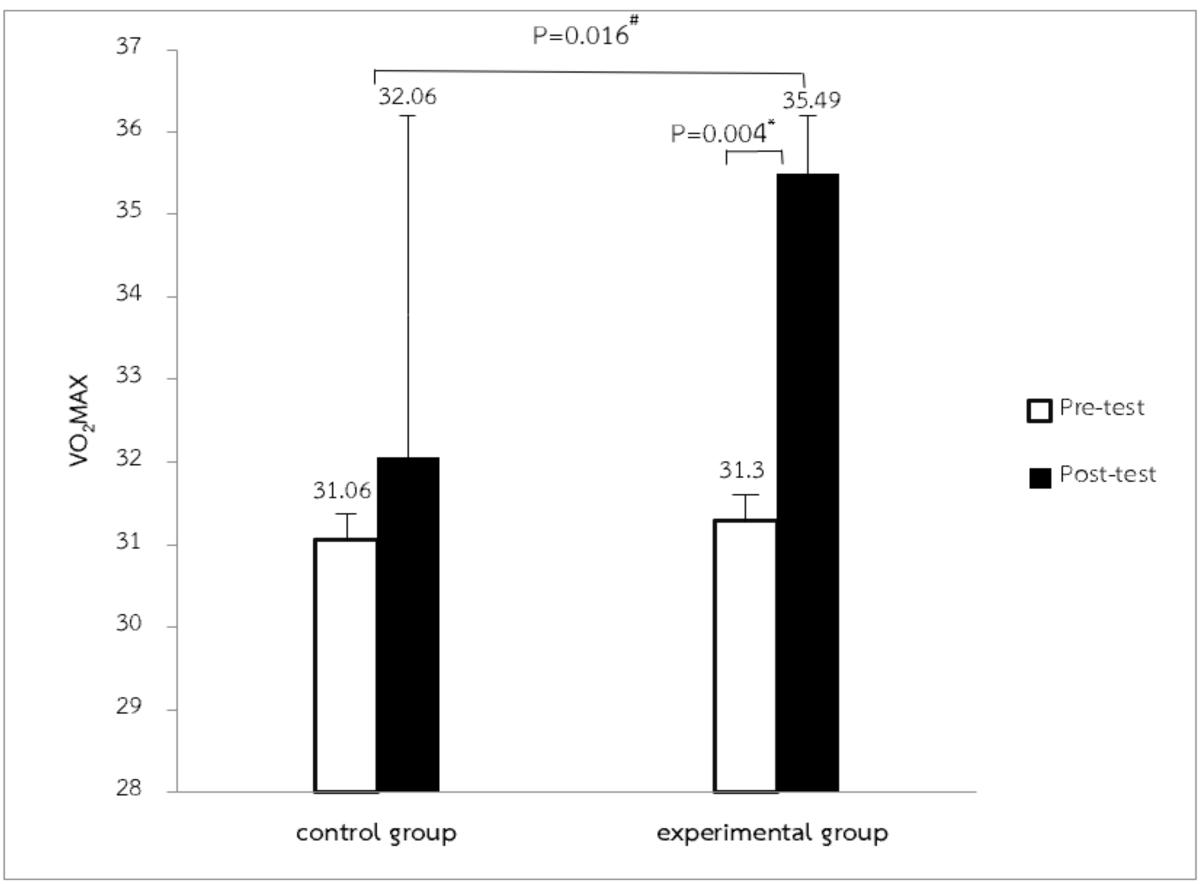

Figure 2. Change in VO_2 Max Before and After Training.

DISCUSSION

The purpose of this study was to investigate the effectiveness of a moderate-intensity drumstick exercise (Pound®) on VO_2 Max, body composition, and overall satisfaction in overweight youths. The participants included overweight students aged 19 to 24 years (with BMI ranging from 23.0 to 24.9 kg/m²). Data collection was carried out using both quantitative and qualitative methods. Quantitative data were collected through measurements of body composition and VO_2 Max. The results were analyzed using statistical software to determine the mean, standard deviation, and baseline values for body composition and VO_2 Max in both the Control Group and the Experimental Group before and after the training. The analysis also included comparisons of intra-group differences before and after the training, as well as between-group differences after training. Also, the mean, standard deviation, and satisfaction levels of the participants were assessed. The results of the study on the effectiveness of a 6-week moderate-intensity exercise (Pound®) on VO_2 Max, body composition, and satisfaction in overweight youths are presented as follows.

Body Composition

After implementing the Pound® exercise program, the Experimental Group was more effectively in improving body composition. Before and after training, the following changes were observed: mean weight, BMI, fat mass, and body fat percentage decreased, while mean muscle mass increased since this exercise enhanced energy expenditure (28). The body can burn fat for energy because the aerobic energy system relies on oxygen in the process of metabolism. This system uses both carbohydrates and fat for energy. During prolonged exercise, carbohydrates are utilized first. As exercise duration increases, the body gradually shifts to using more fat, which eventually becomes the primary source of energy production.

The American College of Sports Medicine (34) recommends that moderate-intensity exercise can enhance energy expenditure that contributes to weight loss. This is in line with Ryskey (28), which noted that Pound® can burn an average of 238 kcal (6.3 kcal/min) during 38 minutes of activity, while a 40-minute session can increase metabolic energy expenditure, burning an average of 387 kcal (9.7 kcal/min). Women burn an average of 384 kcal, while men burn 444 kcal during a 60-minute session. This aligns with the findings of Romero (27), reporting that heavy metal drummers burned an average of 518 kcal/h (8.6 kcal/min), while African drumming burned an average of 412 kcal/h (6.9 kcal/min). Similarly, Smith et al. (33) used heart rate (HR) measurements to estimate the energy expenditure of drumming and found that the average energy expenditure of drumming was 623 kcal/h (10.4 kcal/min), which is significantly higher than the other studies.

Also, exercise that enhances the body's ability to use oxygen also improves the muscles' capacity to use fat as an energy source and increases the efficiency of enzymes involved in fat metabolism. It also increases the size and number of mitochondria, which is important in using oxygen to break down nutrients. This leads to the processes of the beta-oxidation, the tricarboxylic acid cycle, and the electron transport chain, which contribute to the production of ATP for energy. These processes led to changes in body fat in the Experimental Group. The increased the utilization of fat that also resulted in a reduction in body fat percentage, which led to a decrease in body mass index (BMI) and body weight.

Maximal Oxygen Uptake (VO_2 Max)
The Pound® exercise was a moderate-intensity exercise program. The mean values of the Experimental Group increased after the 6-week training period, with a training duration of 30 minutes per day. The exercise intensity was determined using the Borg RPE 6-20. Pound® had an RPE value of 12 to 14, indicating that it was a moderate-intensity exercise, excluding the warm-up and cool-down phases. It is recommended that individuals exercise within 64 to 94% of their maximum heart rate (HRmax) and 40 to 85% of their maximum oxygen uptake (VO_2 Max) to achieve cardiovascular benefits. The present study found that the participants exercised at an average of 72% of their HRmax and 41% of their VO_2 Max, placing them within the moderate-intensity range (28). These findings are consistent with a study by Smith et al (33) that reported heavy metal drummers exercised at 55 to 70% of their HRmax and 42 to 45% of their VO_2 Max, respectively.

ACSM (2) recommends that exercise aimed at producing cardiovascular improvements should be performed at an intensity of 70 to 94% of HRmax. To enhance VO_2 Max, exercise should be performed at an intensity of 60 to 90% of HRmax to achieve improvements in aerobic capacity. The heart rate during Pound® training ranges from 64% to 94% that led to changes in the cardiovascular system and an increase in VO_2 Max. In addition to exercise intensity, the duration and frequency of training are also key factors contributing to these improvements. VO_2 Max is influenced by the efficiency of the circulatory system, particularly the capillaries, which help to deliver oxygen to the cells. An increase in capillary density plays a significant role in enhancing VO_2 Max, especially the exercise that affects the increase of capillaries in the muscles (21). In this study, the training duration was approximately 30 minutes per session, with a frequency of 3 days per week, which contributed to an increase in VO_2 Max. To improve endurance, exercise should be performed for at least 20 minutes per session, 3 to 5 days per week (2). According to Romero (27), the mean VO_2 Max for the drummers was 40.2 ± 9.5 mL/kg/min, which suggests that drumming is a moderate aerobic activity for adult men. The mean MET value was 6.3 ± 1.4, indicating a high-intensity activity.

Additionally, the American College of Sports Medicine (22) reported that the mean VO_2 Max during drumming at maximum speed was approximately 90% of the drummers' VO_2 Max. In the present study, when comparing the performance of Pound® between the Experimental Group and the Control Group, no significant differences were observed. This may be due to the fact that the Pound® exercise program includes variations of intensity, namely light, moderate, and high, with exercise durations of 15, 30, and 45 minutes. In this study, a 30-minute duration was selected that corresponded to a moderate training intensity, and the training was conducted over a 6-week period. It is possible that this intensity level did not reach the training threshold for significant changes between the Groups. As a result, no statistically significant differences were observed between the Groups.

Satisfaction
The satisfaction among the participants who participated in the Pound® exercise program was assessed. The results showed that the participants' overall satisfaction was at the highest level, with the mean score of 4.77. It was also found that the participants were particularly satisfied with Item 4, stating that Pound® helped to increase muscle strength (gaining the highest mean score of 4.90), followed by Item 9, assessing how much fun, cheerfulness, joy, and energy the participants experienced during the workout (a mean score of 4.85). These high satisfaction scores can be attributed to the nature of Pound®, which

engages all muscle groups while incorporating rhythm and fun with modern music (18), resulting in the increase in the participants' satisfaction.

CONCLUSIONS

Pound® can be incorporated into a fat-burning routine for overweight people, with a duration of at least 6 weeks. It also offers a fresh and engaging way to exercise for those wishing to burn body fat and experience a variety of health and fitness benefits.

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Polarized Microcycle Training Improves Performance and Mood States in Amateur Middle-Distance Runners

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ABSTRACT

Changyi C, Sriramatr S, Khamros W. Polarized Microcycle Training Improves Performance and Mood States in Amateur Middle-Distance Runners. Polarized training is a commonly practiced training modality for middle-distance runners. It is interesting to see if this training method can improve performance in amateur athletes. This study examined the effects of polarized training, which was divided into 2 training zones: Low-Intensity Training (LIT) and High-Intensity interval Training (HIIT) over a 6-week period, to determine the effects on both sprint performance (800 m and VO_2 max) and Profile of Mood States (POMS). Twenty-four amateur middle-distance runners from Guangxi Vocational and Technical College of Mechanic and Electricity were divided into a Polarized Training Group (PTG) of 12 and a Control Group (CG) of 12. The PTG consisted of LIT and HIIT training within the same week in an 80:20 ratio, while the Control Group received conventional training. 800-meter time, VO_2 max, and Profile of Mood States (POMS) at pre-, mid-, and post-training were determined. The PTG significantly improved 800-meter running performance and VO_2 max more than the CG ($P < 0.05$) at post-training, while PTG and the CG could improve athlete performance at all stages. In addition, POMS found that the PTG Group had better mood in various dimensions such as Tension, Depression, Anger, Vigor, Self-Esteem, and Total Mood Disturbance. The Polarized training significantly affected both running performance and mood in the middle-distance runners. It also improved mood and reduced training stress. Polarized training is a good choice for improving running performance and mood control in amateur runners with limited training time.

Key Words: Middle Distance, Polarized Training, Running, POMS

INTRODUCTION

From the study of the principle of "Polarized Training", which is a type of training that divides the intensity of training into 2 main parts: (a) low-intensity training (Zone 1); and (b) high-intensity training (Zone 3) by using a clear proportion of training, such as 80% of training in Zone 1 and 20% in Zone 3 (8), it was found that Polarized Training can help improve running performance in middle-distance runners. This is especially the case with amateur runners who do not have enough training structure and have limited training time. This training approach not only improves the runners' physical performance, but also influences their mood and motivation to train (14). The Polarized training is popular among professional runners because it can effectively increase cardiovascular endurance (2). By training at a low intensity, the body has time to recover and adapt, which reduces the risk of overtraining, and it can also increase running speed during high-intensity intervals (19).

Hence, in the case of amateur runners with limited training time, polarized training may help develop a balance between training that is not too intense and the right challenge to increase physical and mental performance (15) that stimulates better development, especially when compared to high-intensity training or threshold training with the risk of overtraining (4). In fact, in research that investigated Polarized training, it was found that runners who trained according to the Polarized approach were able to improve their performance in middle-distance running, which increased their speed and reduced race time (7). Therefore, Polarized training is a potential alternative for improving both physical and mental fitness for amateur runners who do not have a good training structure, lack the motivation to train, and the emotional state from training in a short period of time, but want good results.

In applying Polarized training to amateur runners with limited experience, it is very important to allocate the time and intensity of training appropriately to current performance. Polarized training may also allow the development of physical performance in a short period of time without the fatigue or injury that comes from training at too high an intensity (12). In this type of training, runners can achieve good results in terms of both improving physical performance and promoting better mood, which in turn increases motivation to train in the long run. Thus, training that balances low and high intensity zones while also improves running performance in amateur runners, reduces the risk of overtraining, and promotes mood and motivation to train may make the training program suitable for runners with limited time and training experience.

The intriguing question of whether Polarized training in the context of amateur athletes can help them achieve short-term training success and support their emotional state remains to be seen. Hence, the purpose of this study was to investigate whether polarization training affects performance over a 6-week period and its side effects on emotional state in amateur middle-distance runners.

METHODS

Subjects

The study participant consists of 24 male middle-distance runners from Guangxi Vocational and Technical College of Mechanic and Electricity were selected using purposive sampling. The participants were randomly assigned to 2 groups: the Polarized Training Group (PTG, i.e., the Experimental) Group and the Control Group, each consisting of 12 runners. The

Inclusion Criteria was the runner must be with at least 1 year of competitive middle-distance running experience (800 m - 1500 m), not had injury for the past 6 months, joint and signed consent form acknowledging participation. The **Exclusion Criteria** consisted of anyone who had an injury or health issues during the study. This research was approved by the Ethic committee of the Guangxi Vocational College of Technology and Business (GXGS-2025BS-0320).

Experimental Design

All the participants understood the purpose of the training program, as well as the objectives, and the requirements of the study prior to signing a consent form to voluntary participation in the study.

The Polarized Training Program (PTG) consisted of 6-weeks of polarized training that involved low-intensity training (LIT) and high-intensity interval training (HIIT). Each week included five training days, focusing on 80% low-intensity and 20% high-intensity training. The Control Group (CG) was trained with a general, non-specific program.

The testing consisted of pre-period, mid-period, and post-training period. The participants underwent an 800 meter and 1500-meter test on the same day, which was followed by a VO_2 max test (Yo-Yo IR1 test). Each testing had a rest period of approximately 48 hours. In the post-test after 3 weeks, the test was performed after the last training session within the microcycle. At the end of the test, there was a 24-hour rest period and then the training session was resumed.

Training Protocol

The training was conducted in a standard track and field stadium. Before the training, the program was explained to the athletes. During the training, there were 3 research assistants who covered the entire field to encourage and control the athletes to exert force at the specified intensity. Since the athletes were amateurs, the researcher had prepared for emergency equipment to help in case of an emergency. All the training was controlled by Mi Band 9 (Xiaomi Corporation, China); (17) r = 0.72 to 0.69 and the data were rechecked with the Mi Fitness application to ensure that the data matched the training program as much as possible.

First stage (1 to 3 Weeks), for 3 weeks training: (a) Low-Intensity Training (LIT); 1 x 60 min continuous training performed 4 times a week and High-Intensity Interval Training (HIIT); 5 rep x 3 min active rest 3 min performed 1 time per week. After 3 weeks training, the load was adjusted to the Second stage.

Second stage (Weeks 4 **to** 6), Low-Intensity Training (LIT); 1 x 70 min continuous training performed 4 times a week and High-Intensity Interval Training (HIIT); 6 rep x 4 min active rest 3 min) performed 1 time per week. All in all, the ratio was 80:20% within 1 week.

Table 1 Training Program Schedule.

Group	Pre-Test	Training Load (Weeks 1-3)	Mid-Test	Training Load (Weeks 4-6)	Post-Test
Polarized Training Group (PTG)	800-meter and VO_2 Max Test	LIT; 1 x 60 min x 60 to 65% HRmax HIIT; 5 rep x 3 min Rest 3 min) 90-95% HRmax + Active Rest	800-meter and VO_2 Max Test	LIT; 1 x 70 min x 60 to 65% HRmax HIIT; 6 rep x 4 min Rest 3 min) 90-95% HRmax + Active Rest	800-meter and VO_2 Max Test
Control Group (CG)		General Training Program		General Training Program	
Other Assessments	Profile of Mood States Measured before Every Week Training (First Training Session Each Week)				

Measurements

VO_2 max

A standardized test method, Yo-Yo IR1, was used to test the oxygen consumption rate of athletes. Before the test, the sound signal and running distance were explained, and the research assistant encouraged them to do their best. When the results were obtained, they were calculated to find VO_2 max using formular Bangsbo et al. (3); VO_2 max = (Distance (m) × 0.0084) + 36.4.

800-Meter Test

The 800-Meter Test was a middle-distance race tests that was conducted using a stopwatch (Casio HS-3V) with the "Set" command signal followed by a whistle, which simulating a real race situation.

The Profile of Mood States (POMS)

The athletes were asked to complete the Profile of Mood States (POMS) questionnaire prior to each weekly training session to assess how the training affected their mood. The Profile of Mood States (POMS) questionnaire consisted of 40 items, and it was rated on a 5-point scale. Each item was grouped into 7 main categories: Tension, Anger, Fatigue, Depression, Self-esteem, Vigor, and Confusion. A Total Mood Disturbance (TMD) was calculated by adding all of the items together using the POMS formula (11): (Tension + Anger + Fatigue + Depression + Confusion) - (Vigor + Self-esteem).

Statistical Analyses

Data were analyzed using SPSS (version 24). Means and standard as (mean ± SD) deviations were presented for the variables 800-meter, VO_2 max test, and Profile of Mood States (POMS). The Shapiro-Wilk test was used to check the normality of the data distribution to ensure that the parametric test could be used. The two-way analysis of variance with repeated measures was used to analyze the interaction between the training program x time on the 800-meter and VO_2 max test. The independent-samples *t*-test was used to compare group differences for Profile of Mood States (POMS) scores. Statistical significance was set at $P < 0.05$.

RESULTS

The results showed that in the 800-meter run, there was an interaction between time x training program ($P = 0.048$), where the PTG Group tended to improve significantly more than the CG ($P < 0.05$). Both Groups had significant within-group differences between Group all periods ($P < 0.05$). All the results are shown in Tables 2 and 3.

The VO_2 max showed a significant interaction between time x group ($P = 0.006$), with the PTG showing continuous higher improvement than the CG, and there was a difference between the Groups in post training ($P < 0.05$). Both Groups had significant within-group differences between the time periods pre- and post-training ($P < 0.05$). All results show presented in Tables 4 and 5.

In terms of mood according to the POMS assessment, the PTG scored significantly better than the CG in Tension, Depression, Anger, Vigor, Self-esteem, Confusion, and TMD ($P < 0.05$), while no difference was found in Fatigue ($P > 0.05$). All the data are present in Figure 1.

Table 1. The Physical Characteristics of the Participants.

Physical Characteristics	Mean ± SD
Age (years)	19.33 ± 0.65
Height (cm)	174.25 ± 3.47
Weight (kg)	62.92 ± 7.62
800 (sec)	163.81 ± 14.44
1500 (sec)	343.87 ± 28.47
VO_2 Max (ml/kg/min)	50.42 ± 1.19

Table 2. The Result of Test Within Group in 800-Meter Test.

Group	Pre-Test	MID-Test	Post-Test	P value
PTG (sec)	162.42±16.10	155.20±12.17	148.40±9.28	0.001*
CG (sec)	163.81±14.44	160.45±13.06	155.51±12.79	0.001*

CG = Control Group, **PTG** = Polarized Training Group. *P < 0.05 indicates statistically significant difference.

Table 3. The Result of Test Between Group in 800-Meter Test.

Group	Pre-Test	MID-Test	Post-Test
PTG (sec)	162.42 ± 16.10	155.20 ± 12.17	148.40 ± 9.28
CG (sec)	163.81 ± 14.44	160.45 ± 13.06	155.51 ± 12.79
P value	0.826	0.319	0.013*

CG = Control Group, **PTG** = Polarized Training Group. *P < 0.05 indicates statistically significant difference.

Table 4. The Result of Test Between Group in VO_2 Max from Yo-Yo IR1 Test.

Group	Pre-Test	MID-Test	Post-Test	P value
PTG (sec)	50.21 ± 1.19	50.71 ± 1.60	51.36 ± 1.45	0.001*
CG (sec)	50.42 ± 1.19	50.28 ± 1.05	50.63 ± 1.02	0.001*

CG = Control Group, PTG = Polarized Training Group. *P < 0.05 indicates statistically significant difference

Table 5. The Result of Test Between Group in VO_2 Max from Yo-Yo IR1 Test.

Group	Pre-Test	MID-Test	Post-Test
PTG (sec)	50.21 ± 1.19	50.71 ± 1.60	51.36 ± 1.45
CG (sec)	50.42 ± 1.19	50.28 ± 1.05	50.63 ± 1.02
P value	0.738	0.442	0.016

CG = Control Group, PTG = Polarized Training Group. *P < 0.05 indicates statistically significant difference.

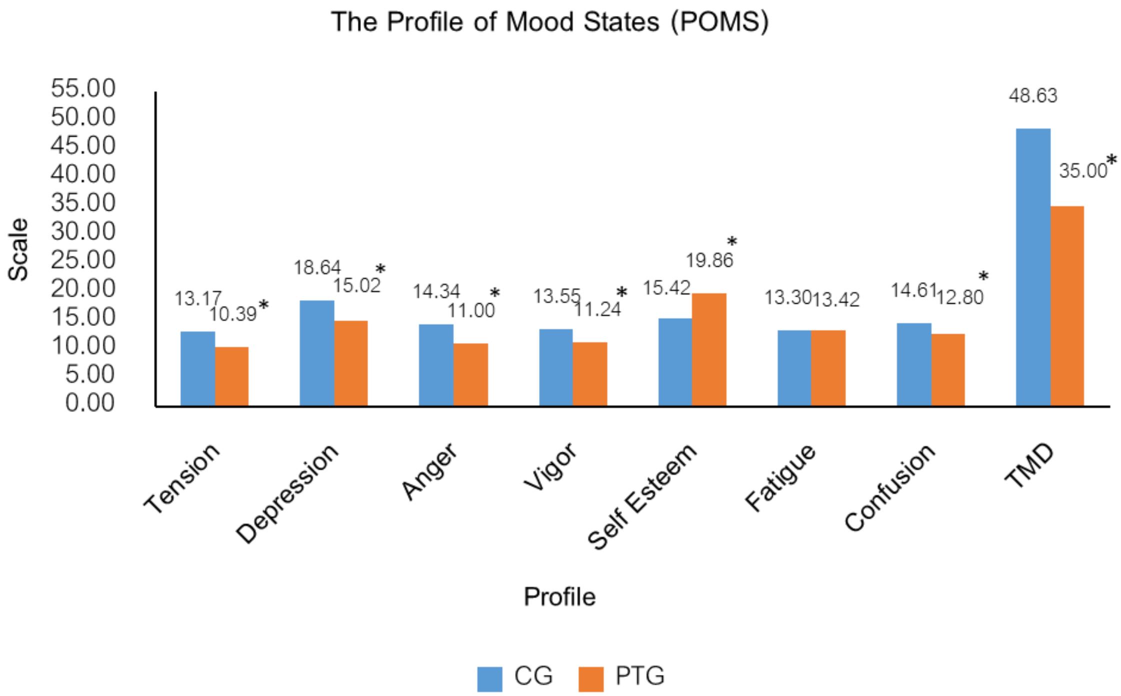

Figure 1. Differences in The Profile of Mood States (POMS) Each Week.
*P < 0.05 indicates statistically significant difference.

DISCUSSION

The study found that after the 6-week polarized microcycle trial, the athletes who participated in the training improved their running performance and the differences between the Polarized Training Group (PTG) and the Control Group (CG) were not significant at each time point. Thus, the findings indicated that the polarized training significantly improved middle-distance and long-distance running performance in microcycle training, which is consistent with the conclusions reported by Muñoz et al. (14). The Polarized training significantly improved middle-distance running performance, and there were significant differences between the Groups at each time point, which was possibly due to the short test duration that affected the data to change between the Groups. This can be explained by the fact that the 800 m is a mixed energy event (9) that requires the optimization of all 3 energy distribution systems. The moderate intensity training of the Control Group was sufficient to induce short-term adaptations of the glycolytic and aerobic systems (9).

Any structured training (including the moderate intensity training of the Control Group) may improve the efficiency of mixed energy expenditure, resulting in no significant differences between the Groups. Middle-distance running, particularly the 800-meter race, is a race that requires both aerobic and anaerobic energy expenditure. Approximately 70% of the energy expenditure in the 800-meter race comes from anaerobic metabolism, while in the 1500-meter race, approximately 50% of the energy expenditure comes from aerobic metabolism and 50% from anaerobic metabolism (1). Thus, VO_2 max is an important parameter for the development of athlete performance.

Oxygen uptake was significantly changed in the CG and the PTG. Significant changes in VO_2 max values were observed in both the Control Group and the PTG, which is consistent with the findings of Stöggl and Sperlich (21), who observed significant improvements in VO_2 max values in the PTG, despite similar changes in maximal oxygen consumption in the CG. However, it is considered a change in aerobic capacity resulting from physiological changes after training. The PTG was significantly higher than the CG. Our results are consistent with several previous studies. These studies have shown that polarized training is more effective in improving aerobic capacity (5,10,11,20). Also, the previous studies have shown that the PTG is more effective than the traditional moderate-intensity training in increasing maximum oxygen consumption (VO_2 max) (14,15). This could be explained by the unique advantages of the high/low intensity combination in PTG, which has a significant advantage in inducing physiological adaptations related to endurance.

Although training in the CG may not be effective from the polarized training perspective, it can induce short-term improvements in physiological capacity that are directly related to anaerobic endurance in middle-distance races. This effect is similar to the effect produced by combining high/low intensity in a polarized group (14). However, our results confirm previous research and show that incorporating polarized training into a training program has an effect that may translate into a long-term training advantage, and if the length of the training period is increased, similar conclusions to those of Muñoz et al. (21).

In the training of amateur athletes, fatigue is a factor that may reduce motivation to train. The stress of high-intensity or unstructured training can influence the emotional and mental state of athletes, which of course directly affects their performance in sports (13). This study showed that the results of POMS are related to sports performance (6), which is consistent with the results of the study that found PTG had lower POMS levels than the CG and that polarized training can improve the performance of middle-distance runners better than CG. In addition, POMS can help monitor and improve athletes' emotional state and help adjust training to improve performance and prevent training stress (18).

Although the performance of both the CG and the PTG is not very different, the PTG has been shown to have a better effect on amateur athletes than the CG. The results can be explained by the fact that polarized training significantly improves athletes' physiological and psychological cognition. In addition, all forms of running have an effect on reducing stress and depression, increasing vitality, and it helps improve sleep quality in amateur runners (6). The results from POMS confirm that training with the Polarized training program, which is a training program that uses low loads rather than heavy loads, can significantly reduce stress and emotional states.

CONCLUSIONS

The results of this study show that even in a group of amateur middle-distance runners, polarized training can improve athlete performance even in a short training period. In addition, polarized training has a positive effect on the emotional state of the athletes compared to traditional training. The significance of this study shows that even in a group of amateur athletes who do not train consistently throughout the year, polarized training can significantly improve performance in a short period of time.

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Comparative Analysis of Physical and Mental Workload in Amateur Volleyball Teams With and Without a Libero Player

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ABSTRACT

Yongjun P, Phongsri K, Kumphuang C, Rakwal R, Khamros W. Comparative Analysis of Physical and Mental Workload in Amateur Volleyball Teams With and Without a Libero Player. The Libero is a key defensive player for receiving serves and defending attacks, which can have an important impact on the players' movement and mental load during a match. The purpose of this study was to compare the physical and mental workload of playing with and without the Libero in an amateur volleyball team. A randomized crossover design of 12 male amateur university students with a mean age of 19.17 ± 1.11 years were used to study the effects of the Libero, the match was simulated in 4 conditions: Team A With a Libero vs. Team B Without a Libero, Team A Without a Libero vs. Team B With a Libero, both teams with a Libero, and both teams without a Libero. The results indicated that AvrHR and PHR of the Libero team were both lower than the non-Libero team ($P < 0.05$), as well as sRPE of the Libero team being lower than the non-Libero team, and NASA-TLX for the Libero team being lower than the non-Libero team ($P < 0.05$). Both CMJ teams showed reduced jump height after the competition, with no significant difference between teams with or without a Libero. While the Libero helped manage physical and mental workload, they did not affect jump performance.

Key Words: Indoor Sports, Libero, Mental Workload, Volleyball

INTRODUCTION

The Libero is a player specializing in receiving serves, digging balls from attacks, and defending against offenses in volleyball game. They are generally unable to attack or set up games, but having or not having this position in the team can affect the players' physical and mental performance in many ways. Having a Libero player helps to strengthen the team's defense effectively, which has a positive effect on reducing errors in defense (10). This position plays an important role in increasing the ability to respond to attacks and can reduce errors in the receiving phase (21). Meanwhile, a team without the Libero position, players in other positions are more responsible for defending the ball, which can greatly increase the responsibility and pressure on the players. Therefore, the strategic inclusion of a Libero can not only enhance defensive capabilities but also promote better teamwork and coordination among players. In addition, the absence of the libero can reduce the team's overall defensive performance (16). This includes the impact on mental performance (e.g., self-confidence, ability to cope with pressure, and teamwork).

Physiological responses in volleyball are often measured in response to on-field workloads in a match, including speed of movement, ability to defend against attacks, and ability to maintain balance in play (18). In the case of volleyball, the Libero plays a key role in receiving serves and digging from attacks, and the accuracy of these tasks helps to improve the team's defense (22). Additionally, the Libero's performance can significantly influence the overall dynamics of the game, as their effectiveness in these defensive maneuvers often determines the outcome of critical points during matches (1,8,15).

Studies have shown that Liberos tend to have faster and more accurate movements compared to players in other positions, such as setters or outside hitters, who are responsible for various types of attack and defense (9). However, in a match between a team with and without liberos, there may be differences. Players on a team without a Libero may have to move in different ways, since other positions are responsible for more defensive work, which may result in increased fatigue and workload, especially in receiving high-speed balls or defending against opponents' attacks (19). In addition to the physical performance differences, the presence of a libero in a team can also significantly affect the mental performance of the players. Having a Libero player who is skilled in receiving and defending allows the team to focus on their role without having to take on the entire defensive load.

The differences in movement and pressure handling on the field suggest that the presence of a Libero allows the team to be more effective in defense and reduces the workload of players in other positions. In addition, designing a training program that involves appropriate simulation can improve the performance of the team with or without the Libero. The appropriate method can help build defensive confidence for players on teams without a Libero and develop faster and more accurate movement skills, which will help the players to better cope with the opponent's attacks.

Certainly, previous studies (8,9,18,19,22) have shown that the Libero influences the outcome of competitions in professional sports, so this study attempted to find the answer by comparing competitions with and without a Libero in amateur athletes, which may have different effects on physical and mental load in the context of amateur athletes.

METHODS

Subjects

The participants in this study were 12 amateur volleyball players in Yunnan Province, China, who were students of Yunnan Vocational College of Transportation. They had a mean age of 19.17 ± 1.11 years, a mean height of 175.79 ± 4.40 cm, a mean weight of 70.44 ± 4.32 kg, and a mean body mass index (BMI) of 22.85 ± 0.37 kg/m². Other data are shown in Table 1. They were selected by simple random sampling based on the research of Fernandez-Echeverria et al. (5). All selected players received continuous training and were randomly divided into 2 Groups based on their countermovement jump (CMJ) performance data. Group A (Team A) consisted of player numbers 1, 3, 5, 7, 9, and 11, and Group B (Team A) consisted of player numbers 2, 4, 6, 8, 10, and 12. The participants were required to have at least 2 years of amateur competition experience, undergo at least 6 months of intensive training, and attend at least 3 training sessions per week for 6 weeks, as well as have experience in provincial-level or higher competitions but not professional competitions. This research was conducted in accordance with the Human Research Ethics Guidelines by Yunnan Vocational College of Transportation (YJYY-2025SS-55310) based on the guidelines of the Declaration of Helsinki, and all the participants' explicit consent was obtained before starting the research process.

Procedures

Research Design

This research study used a randomized crossover experimental design with 12 male amateur volleyball players. Before entering the baseline measurement process, including height, weight, BMI, Yo-Yo IR1 and the counter-movement jump (CMJ) test, the data were sorted and divided into groups. The simulation of the competition consisted of 4 formats, with different competition conditions in each match: Match 1, Team A With a Libero vs. Team B Without a Libero; Match 2, Team A Without a Libero vs. Team B With a Libero; Match 3, both teams had a Libero player; and Match 4, both teams did not have a Libero player. The order of the experimental conditions was controlled to prevent the effects of fatigue and relearning. After each experimental match, there was a break of at least 48 hours. Data collection was conducted from 6:00 to 7:30 a.m. in an indoor sports hall with a temperature of 18 to 25 degrees Celsius, with at least 3 research assistants with experience in volleyball supervising the entire testing process. The participants were asked to refrain from exercise for at least 24 hours prior to the test and to refrain from eating or drinking energy drinks for 3 hours prior to the test.

Experiment Procedures

Before the simulation, the participants started with a warm-up by jogging around the volleyball court for 3 rounds. Then, they did static and dynamic stretching and light jumping for 5 minutes. After that, the athletes practiced their movement skills, starting with specific movements such as arms and legs, continuing to the whole-body movement for about 3 minutes, followed by practice passing and receiving the ball at a distance not exceeding 3 meters, including practicing movement within 3 meters according to the specified pattern for 2 rounds. Then, all the athletes rested to prepare for the real test for 3 minutes. Before starting the simulation experiment, heart rate was measured using a Polar H10 chest strap, and the rate of perceived exertion (sRPE) was assessed. Then, the athletes entered the simulation competition. Everyone competed under the standard rules, the only difference being the allocation of libero players (with or without liberos in the team) to match the experimental conditions. Throughout the competition, heart rate was continuously monitored. In addition, a research assistant with experience in volleyball acted as a motivator in the role of a coach to make the experimental environment as close to the real situation as possible. After the simulated competition, the CMJ test was repeated immediately to assess the changes in physical fitness after the competition, followed by an assessment of mental workload using the NASA-TLX questionnaire to reflect the mental fatigue caused by each competition condition. All the data were used for analysis and conclusions in the next step.

Countermovement Jump Test

The countermovement jump (CMJ) with arm swing is a widely used method to assess lower-body explosive power, which is important for volleyball players. The CMJ test was performed before and after the match to track changes in muscle power performance (12). It starts with the stance on the force platform with your feet shoulder-width apart and your arms at your sides. Bend your body slightly in a quick tempo and swing your arms back. Bend both legs, straighten your knees, hips, and ankles, and swing your arms forward and over your head. Keep your body straight and try to float as high as possible and land with your knees slightly bent to absorb impact.

Heart Rate Monitoring

The heart rate (HR) was continuously monitored in the simulated competition using the Polar H10 chest strap with Polar Team application for the analysis of average heart rate (AvrHR) and percentage of heart rate (PHR). The heart rate measurements were taken during the competition, with pauses between sets to assess the physiological response to the workload in the conditions with and without the libero. All athletes wore Polar H10 devices throughout the competition to ensure accurate and consistent data collection across the experimental conditions, expressed as a percentage of heart rate.

Rate of Perceived Exertion

The modified rate of perceived exertion (sRPE) was used immediately after each match to assess perceived fatigue on a scale of 1 to 10 (6). The sRPE assessment is considered appropriate for use in volleyball (20).

Mental Workload

The NASA Task Load Index (NASA-TLX) was conducted after the end of each competition condition to measure the level of mental workload that the athletes perceived in team sport. The NASA-TLX is a standard instrument used to measure the subjective mental load and the cognitive load, especially in the context of sports (3). In this study, athletes used the NASA-TLX to reflect their feelings in various aspects, including mental demand, physical demand, temporal demand, performance, effort, and frustration. Using this assessment helps in understanding more clearly the impact of the Libero position on the athletes' mental fatigue and playing strategies.

Statistical Analyses

The quantitative data in this study was analyzed using the computer application SPSS (version 24, IBM Corporation, Illinois, USA). We utilized descriptive statistics to determine the mean ($\bar{X}$) and standard deviation (SD) of the following variables: height, weight, body mass index, average heart rate (AvrHR), Percentage of heart rate (PHR) Countermovement jump (CMJ), the rate of perceived exertion (sRPE), and the NASA task load index (NASA-TLX).

The Shapiro-Wilk test was used to determine whether the data were normally distributed. The statistical significance was defined at $P < 0.05$. The independent sample *t*-test was used to compare AvrHR, PHR sRPE, and NASA-TLX variables among groups. The mix model ANOVA was used to analyze interaction (condition x period) for CMJ variables.

RESULTS

The AvrHR in the with Libero condition was significantly lower than without Libero (149.79 ± 9.18 vs. 162.18 ± 5.79, $P < 0.05$), as was the percentage of PHR, which was significantly (75.34 ± 5.20 vs. 80.85 ± 2.92, $P < 0.05$). For sRPE in the with Libero condition, it was significantly lower than in the Without Libero condition (6.50 ± 0.88 vs. 7.90 ± 0.72, $P < 0.05$). The NASA-TLX score in the with Libero condition was significantly lower than in the without Libero condition (42.75 ± 4.04 vs. 52.95 ± 3.86, $P < 0.05$), all shown in Table 2 and Figure 1.

Table 1. Information on the General Physical Characteristics of the Participants.

Physical Characteristics	Mean±SD
Age (years)	19.17 ± 1.11
Height (cm)	175.79 ± 4.40
Weight (kg)	70.44 ± 4.32
BMI (kg/m^2)	22.85 ± 0.37
VO_2 Max (ml/kg/min)	46.84 ± 2.38

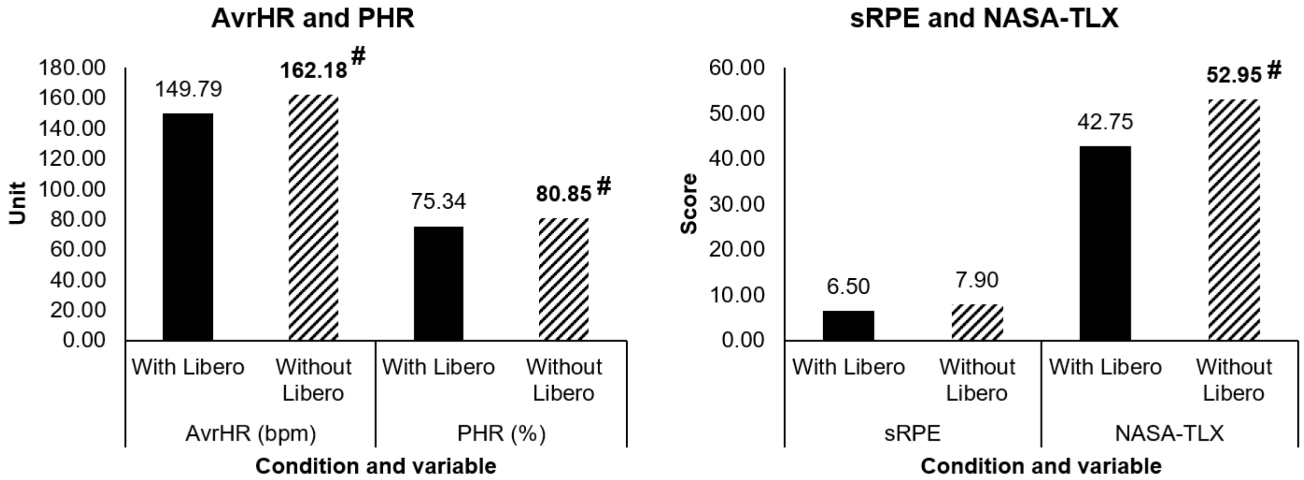
Table 2. A Comparison of the Differences of Variables in Each Condition.

Variables	Group	Mean	P
AvrHR (bpm)	With Libero	149.79 ± 9.18	0.023*
	Without Libero	162.18 ± 5.79 #	
PHR (%)	With Libero	75.34 ± 5.20	0.030*
	Without Libero	80.85 ± 2.92 #	
sRPE	With Libero	6.50 ± 0.88	0.001*
	Without Libero	7.90 ± 0.72 #	
NASA-TLX	With Libero	42.75 ± 4.04	0.001*
	Without Libero	52.95 ± 3.86 #	

*The differences between conditions were statistically significant, $P < 0.05$

#The mean is statistically significantly higher, $P < 0.05$

Note: **AvrHR** = Average Heart Rate, **PHR** = Percentage of Heart Rate, **SPE** = Rated Perceived Exertion, **NASA-TLX** = NASA Task Load Index



#The mean is statistically significantly higher, P < 0.05
Note: **AvrHR** = Average Heart Rate, **PHR** = Percentage of Heart Rate, **sRPE** = Rated Perceived Exertion, **NASA-TLX** = NASA Task Load Index

Figure 1. Difference Average of HR, Percentage HR, RPE, NASA-TLX Variables in With Libero and Without Libero Conditions.

There was no interaction between condition × period of the CMJ test (P = 0.145). However, when analyzing the main effect, there was a statistically significant within-group difference in both conditions (P < 0.05). In the With Libero condition, the mean pre- and post-experimental scores were 50.42±2.45 and 43.63±3.92, respectively, while in the Without Libero condition, the mean pre- and post-experimental scores were 50.90±2.33 and 42.60±4.38, respectively. All results are shown in Table 3.

Table 3. A Mix-Model ANOVA Analysis to Know the Interaction of CMJ in Each Condition.

Condition/Period	Pre-Match	Post-Match	Between Group	Interaction
With Libero	50.42 ± 2.45	43.63 ± 3.92	0.757	0.145
Without Libero	50.90 ± 2.33	42.60 ± 4.38		
Within Group	0.001*			

*The mean is statistically significantly higher, P < 0.05

DISCUSSION

The results of this study found that the average heart rate (AvrHR) and percentage heart rate (PHR) of the team with the Libero player were significantly lower than those of the team without the libero player. This can be explained by the specific role and responsibilities of the Libero player's position, that focused on defense. When the team has a specialized Libero to play defense instead of a non-expert defender, the physical load on the other players overall is reduced that results in a lower average heart rate for the team (1).

In addition, the rate of perceived exertion (sRPE) of the players on teams with a Libero player was found to be lower, reflecting reduced mental and physical fatigue. The presence of Libero player reduced the frequency and intensity of vertical movement and defensive load, resulting in less need for other players, especially outside hitters and setters, to adjust their positions to help receive the ball as much as teams without Liberos (8,20). The reduction in physical workload redundancy leads to lower fatigue perceptions, especially in the sRPE system using the Borg CR-10 scale, which reflects a combination of physical and mental fatigue (6).

In the aspect of stress assessment or mental workload, measured using the NASA-TLX questionnaire, the results showed that the players in the teams with a Libero player had lower average scores than the teams without a Libero player. This can be explained by the fact that the Libero position is primarily responsible for initiating defensive plays, especially in receiving serves and offensive balls, which are continuously trained in a specialized manner so that players in other positions do not have to make urgent decisions in stressful situations as often as teams without a Libero player, resulting in reduced mental workload (3,10,13). In addition, having players with high self-confidence in this position helps create psychological stability for the overall team (4).

The results of the countermovement jump (CMJ) measurement found that the jump height of players in both teams with and without a libero player decreased significantly after the match, but there was no difference between the Groups. This is explained by the neuromuscular load caused by the competition, which has a similar effect on all positions, whether with or without a Libero (11,19). This decrease is a result of accumulated fatigue that the team cannot immediately compensate for after the competition. Although the Libero has a low competition workload and results in a lower workload for the team in other areas, the impact on the overall team in terms of CMJ is not different, because the positions that have to jump frequently, such as middle blocker and opposite, still inevitably bear the same load (7). This is consistent with the fact that jump performance has no relationship with RPE (17).

Overall, the analysis suggests that the role of the Libero has a systemic effect on reducing both the physical and mental workload of the team, especially in terms of AvrHR, PHR, RPE, and mental workload, which are consistently reduced. However, in neuromuscular fatigue indicators such as CMJ, the limitations of having a Libero in reducing physical fatigue at the team level may need to be considered in addition to the substitution strategies, rest, and more specialized training plans. Other factors should also be considered, such as the experience of the Libero, which in world-class teams tends to have players with an older average age, reflecting expertise that positively affects the team's mental workload (14). When combined with precise positioning and strategic assessment in each phase or situation of the game (8), teams with a Libero are more effective in controlling the game's tempo and reducing pressure from various situations. In addition, in different situations, there should be training to prepare mentally to be ready for the competition as well (2).

Limitations in this Study

Although the study demonstrated the effects of having and not having a Libero in amateur volleyball players, it is limited by the fact that the duration of the match or the number of sets were the same across all simulations. Since not specifying a time limit may result in control of other variables, this may not be a suitable method for real competition situations and future studies should consider these factors.

CONCLUSIONS

Although this study focused on amateur volleyball players, the nature of the competition may be similar but may differ in terms of player performance and high-level playing tactics. The evidence clearly shows that the Libero position not only affects the team's energy allocation but also plays a psychological role in enhancing defensive stability, reducing mental workload, and helping the team to manage fatigue more effectively at the match level. Coaches should consider the results of this study together with their competition strategies to apply them in competitions.

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A Pilot Study on the Effects of Adaptive Chair Yoga on Physical Fitness, Mental Health, and Heart Rate Response in Community-Dwelling Older Adults

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ABSTRACT

Sivaphongthongchai A, Mindo D, Nuiden N, Nopthaisong T, Warasit N, Nakkliang K, Thetsana P. A Pilot Study on the Effects of Adaptive Chair Yoga on Physical Fitness, Mental Health, and Heart Rate Response in Community-Dwelling Older Adults. The purpose of this study was to explore the preliminary effects of an 8-week adaptive chair yoga intervention on functional capacity, psychological well-being, and heart rate response among healthy, community-dwelling older adults in Thailand. The intervention program was conducted at Thai-Japan Bangkok Youth Center from October to November 2024. Eight participants (≤60 years) completed 3 supervised chair yoga sessions per week, each comprising pranayama (10 minutes), asana (35 minutes), deep relaxation (10 minutes), and meditation (5 minutes). Pre- and post-intervention assessments included standard physical fitness tests, the WHO-5 Well-Being Index, and heart rate monitoring during 5 yoga phases. Statistically significant improvements were observed in flexibility and muscular endurance: sit-and-reach ($P = 0.005$, $d = 0.72$), back scratch right ($P = 0.018$), two-step test ($P = 0.012$), and 30-second chair stand ($P = 0.019$). WHO-5 scores indicated increased vitality, better sleep, and greater life engagement, particularly in WHO-3, WHO-4, and WHO-5 items ($P < 0.05$). Asana increased HR trend reaching a peak (83.00 ± 9.96 bpm, 85.93 ± 9.44 bpm) in week 1, week 8 while deep relaxation decreased HR trend to 67.67 ± 4.92 bpm, 66.80 ± 6.03 bpm in both weeks. This study supports the feasibility and acceptability of adaptive chair yoga as a low-intensity, health-promoting intervention tailored to older adults. The integration of mindful movement and breathwork appeared to foster physical and emotional well-being with potential regulatory effects on the autonomic nervous system. Despite some limitations, including small sample size, lack of a control group, and HR variability not directly measured, the findings warrant further investigation in larger randomized controlled trials. Adaptive chair yoga could serve as a practical, safe, and inclusive health promotion measure aligned with WHO guidelines to promote healthy aging and fall prevention in older populations.

Key Words: Adaptive Chair Yoga, Health Promotion, Older Adults, Well-Being

INTRODUCTION

Aging populations as a global public health concern has caused crucial transitions in terms of age structure because of higher life expectancy and lower fertility rates (2). In Thailand, there were 2 million older adults aged 60 years in 1990. Thailand had a total population of 66.5 million and a total number of older adults increased to 12 million that accounted for 18% in 2020. Thailand was expected to become a complete age society by 2022 (37). Aging impairs homeostasis in old adults since the aging body is less effective in maintaining and restoring homeostasis compared to the young body. Aging and falling in older adults may lead to fear of falling caused by physical inactivity, poor health, and low confidence (30). A 2010 study reported that half of the older adults aged 80 years fall every year (31).

Heathy aging means the ability to maintain a physically active, socially inclusive lifestyle without illness or disability. Older adults who are actively participating in physical activities to foster their health and well-being are more likely to achieve healthy aging (26). Physical activity can help lower the risk of different diseases and impairment while it can support independence in aging because physical activity positively affects physical health and mental well-being in older adults. Therefore, physical activity that is appropriate for older adults should be introduced to help maintain physical health and mental well-being (19).

Yoga is a mind-body physical activity by integrating basic components, including stretching, postures, meditation, and mindful breathing. Harvard Medical School suggests 4 components of modern yoga: asanas, pranayama, deep relaxation, and meditation (21). Nowadays, yoga can be applied as a health promotion and disease prevention measure in older adults (5). With respect to health benefits, yoga can help improve strength and flexibility in older adults (42). Older adults should participate in yoga because it promotes health-related quality of life and mental well-being (40).

Patanjali's Yoga Sutras addressed the yoga application by stating "Tasya bhumisu viniyogah," which implies that yoga should be applied to satisfy the needs appropriate for each person. The "Viniyoga" concept means providing yoga suitable for individual needs. Yogacharya Krishnamacharya promoted the "Viniyoga" concept (15) developed by T.K.V. Desikachar to meet each individual needs as people grow and change (11). Adaptive chair yoga is applied under the "Viniyoga" concept to satisfy the needs of older adults in which people can practice while sitting in a chair or holding the chair for support (29).

Current literature has reported the health benefits of yoga interventions in various groups of population including overweight elderly women (10), office workers (32), and breast cancer patients (24). However, limited research studies have focused on adaptive chair yoga based on the yoga concept in older adults. The purpose of this pilot study was to explore the preliminary effects of an 8-week adaptive chair yoga intervention on functional capacity, psychological well-being, and heart rate based on the yoga concept and 4 yoga components suggested by Harvard in healthy, community-dwelling older adults aged 60 years or more.

METHODS

Participants

Older adults who volunteered to participate in this study were recruited from Thai-Japan Bangkok Youth Center. They met the following ***inclusion criteria***: (a) adults aged 60 years or more; (b) Thai native speakers; (d) normal BMI between 18.5 and 23.0 (43); (e) normal heart rate between 60 and 100 bpm (4); and (f) normal SBP of <120 mmHg and/or DBP <80 mmHg (34). The ***exclusion criteria*** included: (a) volunteers who were advised by doctors not to perform any exercises; (b) volunteers who practiced yoga or other planned exercises for the last 2 months; (c) volunteers who had health problems related to mobility, such as paralysis, inability to walk, sit or stand that would affect yoga exercises; (d) volunteers with significant visual impairment; and (e) volunteers who had major surgery in the last year or planned to undergo future surgeries. The ***withdrawal criteria*** were: (a) the participants could not complete at least 80% of the exercise program; and (b) the participant requested to withdraw from the program.

The researchers described the research objectives and the significance to the participants. The researchers asserted that their rights were protected. Their identity and participation were kept confidential, and their privacy was well respected. All the participants acknowledged that they volunteered to participate in this study, and they could drop out from the study if they wanted to. Each participant gave informed consent before taking part in the study.

Study Design

The design was a pretest-post test pilot study within 1 group. The physical fitness outcomes and mental well-being were measured as pretest (baseline) in week 1 and posttest in week 8. The 5 measures assessing physical health outcomes included the: (1) Sit-and-Reach Test; (2) Back Scratch Test; (3) Two-Step Distance Test; (4) 30-Second Chair-Stand Test; and (5) 2-Minute Step Test while the WHO-5 Well-Being Index was used to measure mental well-being. The results of HR (heart rate) trend before yoga practice and during yoga practice including asana, pranayama, deep relaxation, and meditation within week 1 and week 8 were recorded.

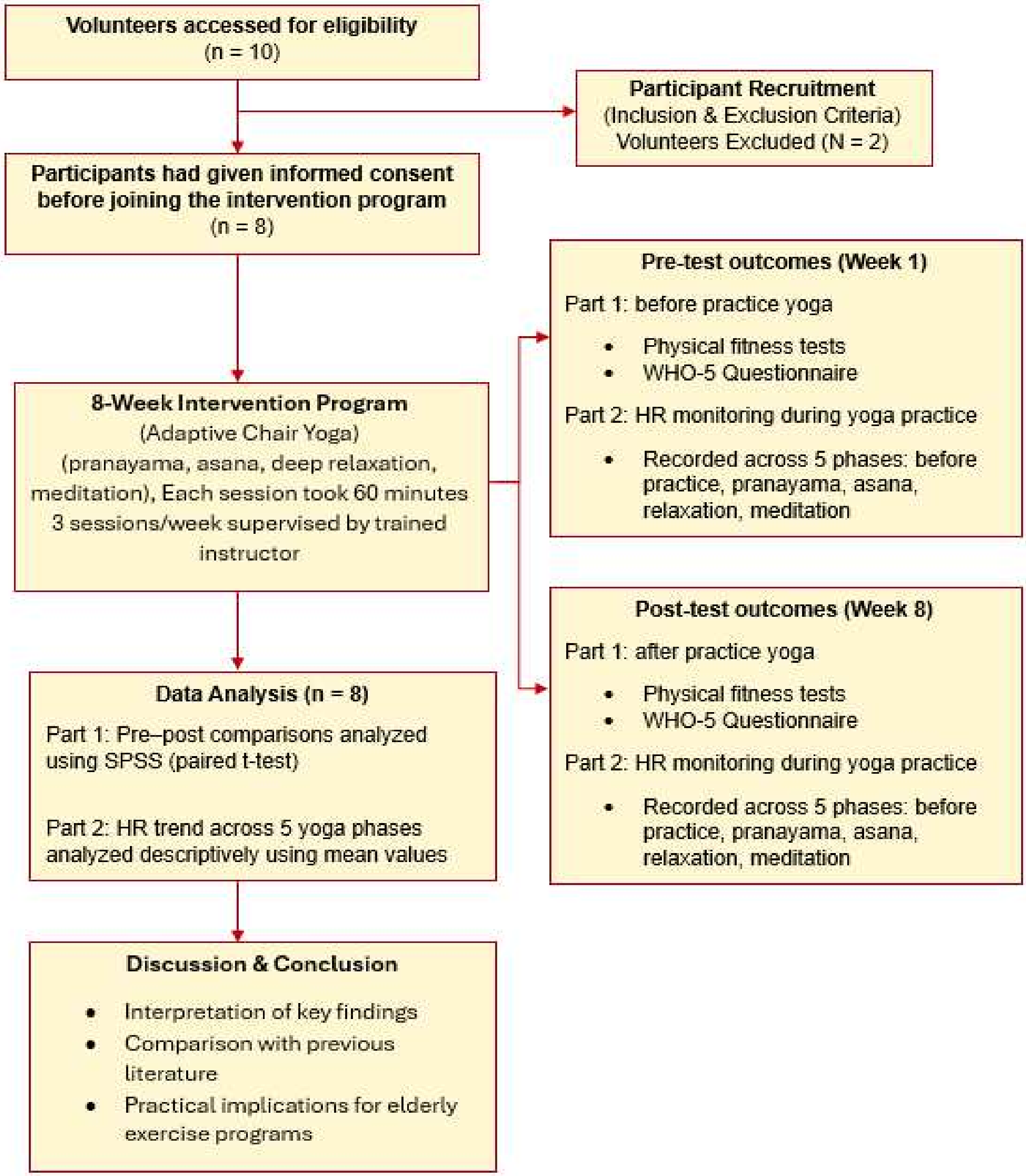
The Intervention Program "Adaptive Chair Yoga"

The 8-week intervention program was conducted at Thai-Japan Bangkok Youth Center from October to November 2024. The primary author, Dr. Akarat Sivaphongthongchai[E-RYT 500, RCYT, YACEP], was the instructor of adaptive chair yoga. The instructor is a Registered Yoga Teacher with The Yoga Alliance. A total number of 8 participants took part in 3 exercise sessions/week on Monday, Wednesday, and Friday from 10 to 11 o'clock. Each exercise session lasted 60 minutes. Therefore, all the participants practiced 180 minutes/week in total. The sequence of each exercise session included pranayama (breathing exercise) for 10 minutes, asana (yoga poses) for 35 minutes, deep relaxation for 10 minutes, and meditation for 5 minutes. The sequence of 15 yoga poses (13) practiced in each session is explained in Table 1.

Table 1. The Sequence of 15 Yoga Poses.

No.	Asana poses	Major movement	Main muscle/system target
1	Tāḍāsana (Mountain Pose)	Grounding, Axial Extension	core awareness
2	Utkatāsana (Chair Pose)	Strength, Stability	legs, core and glutes
3	Utthita Pādāṅguṣṭhāsana (Standing Big Toe Hold Pose)	Hip & Leg Activation	hamstrings and psoas
4	Cakravākāsana (Cat Cow Pose)	Flexion–Extension	spine and coordination
5	Ardha Uttānāsana (Halfway Lift Pose)	Forward Bend	back and hamstrings
6	Paścimatānāsana (Seated Forward Bend Pose)	Deep Forward Bend	Parasympathetic, deep posterior chain
7	Anuvittāsana (Standing Backbend pose)	Backbend	chest, psoas and diaphragm
8	Pārśva Bhāga (Palm Tree Pose Side Bend)	Side Stretch	lats, ribs and obliques
9	Tiryaka Tāḍāsana (Swaying Palm Tree Pose)	Standing Side Stretch	lateral balance
10	Pārśva Paścimatānāsana (Side Lying Forward Bend Pose)	Seated Twist	thoracic spine and internal organs
11	Jānu Śīrṣāsana (Head-to-Knee Pose)	Asymmetric Twist + Forward Bend	one-side integration
12	Urdhva Baddhāṅguliyāsana (Upward Bound Finger Pose)	Overhead Reach	shoulders and thoracic expansion
13	Baddha Koṇāsana (Butterfly Pose)	Hip Opening	pelvic floor – groin
14	Supta Pāvān Muktāsana (Reclining Wind Relieving Pose)	Wind-Relieving (Passive Flexion)	lumbar release – digestion
15	Śavāsana (Corpse Pose)	Rest & Integration	Nervous system, internal homeostasis

Figure 1. The Flowchart of this Study.



Measurements

The Sit-and Reach Test was used to assess the flexibility of the lower back and hamstrings. Each participant was asked to bend toward the toes while maintaining the back and the extended leg straight and staying stretched for 2 seconds. The researchers recorded the distance in centimeters to one decimal point between the fingertips and toes. The score was counted as positive when the fingers touched the toes. The score was counted as negative when the fingers did not touch the toes. Each participant performed the test twice (7).

The Back Scratch Test, also known as the Zipper Test, measures the upper extremities by how close both hands can reach behind the back (38). The Back Scratch Test was used to measure shoulder flexibility. The researchers recorded the distance between the fingers. The score was counted as negative when one hand did not touch the other. The score was counted as positive when both hands touched each other.

The Two-Step Test measured the walking ability of the participants (25). The values of this test were calculated from the maximum length of 2 steps (cm)/participant's height (cm) (22). Each participant was asked to perform it twice and the best value was recorded (20).

The 30-Second Chair-Stand Test was employed to measure physical performance in terms of lower body strength. Each participant was asked to perform stands within 30 seconds with both hands crossed on his or her chest. A previous study proposed a cut-off point at 8 stands while 8 stands or lower could be interpreted as a risk of functional decline (6). In the 2-Minute Step Test, each participant was asked to walk in place as fast as possible for 2 minutes and to lift the knees to the height of his or her iliac crest while standing (3).

The 5-item World Health Organization Well-Being Index (WHO-5) or the WHO-5 questionnaire is a set of 5-item questionnaires employed extensively in research worldwide to measure subjective psychological well-being. Current research from various study fields has applied the WHO-5 questionnaire as an effective measure (39). The WHO-5 questionnaire consists of 5 items with a 6-point Likert scale, ranging from 0 (at no time) to 5 (all the time) and the total scores range from 0 to 100. The scores lower than 50 mean poor well-being while the higher scores mean better well-being (28).

Heart rate (HR) can be measured by the Polar H10 heart rate sensor with a chest strap, which is a wearable, electrical device to measure heart rate with precision and comfort. It is a safe, reliable, and convenient measurement tool to record heart rate and heart rate variability (33).

Statistical Analysis

The demographic information of 8 participants was analyzed and described in means and standard deviations (SD). Their data ($n = 8$) were analyzed in 2 parts. Part 1, including pre–post comparisons of physical health and mental well-being outcomes was analyzed using paired *t*-tests in SPSS version 24. Statistical significance for the *t*-tests was set at $P < 0.05$. Part 2, including HR trends across 5 yoga phases, was analyzed descriptively using mean values.

RESULTS

The results on the demographic information of all the participants were similar without significant differences (P > 0.05) (Table 2). Most of the participants were five females, and the others were three males. The mean age, weight, height, BMI, and resting HR were 65.60 years, 53.77 kg, 154.67 cm, 23.19 kg/m^2, and 72.07 beats/minute, respectively.

Table 2. The Demographic Information of All the Participants.

Demographic N=8 (F=5, M=3)	Mean + SD
Age (years)	65.60 ± 5.04
Weight (kg)	53.77 ± 14.77
Height (cm)	154.67 ± 6.56
BMI (kg/m^2)	23.19 ± 3.39
Resting heart rate (bpm)	72.07 ± 6.68

Physical Fitness Outcomes

Table 3 demonstrates the effects on physical health outcomes with P-values and Cohen's d before and after yoga practice. Adaptive chair yoga improved the participants' flexibility in the Sit and Reach Test by decreasing the mean reach distance from 12.27 ± 6.11 cm at baseline to 8.60 ± 3.79 cm in week 8 with statistical significance (P = 0.005) and moderate to large effect size (Cohen's d = 0.722).

Adaptive chair yoga positively affected the distance in the Back Scratch Test by decreasing the mean reach distance on the right side from 8.93 ± 3.81 cm at baseline to 7.00 ± 4.23 cm in week 8 with a statistical significance (P = 0.018) and moderate effect size (Cohen's d = 0.479). However, the mean distance on the left side decreased slightly from 9.33 ± 4.65 cm in week 1 to 9.07 ± 4.37 cm in week 8, which was not a statistically significant difference.

Moreover, adaptive chair yoga promoted lower-limb functional capacity in the Two-Step Test by increasing the mean scores from 1.27 ± 0.19 at baseline to 1.33 ± 0.22 in week 8, which was a statistically significant difference (P = 0.012) with small to moderate effect size (Cohen's d = 0.292).

Adaptive chair yoga promoted the 30-Second Chair-Stand Test performance by significantly increasing the average number of repetitions from 13.20 ± 4.00 at baseline to 15.87 ± 5.00 in week 8 (P = 0.019) with a moderate effect size (Cohen's d = 0.590). Finally, the adaptive chair yoga improved the 2-Minute Step Test performance by increasing the average steps from 81.33 ± 17.52 at baseline to 84.47 ± 14.73 in week 8.

Table 3. Physical Health Outcomes at Baseline (Week 1) and Week 8.

Physical health tests (n=8)	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	P-value	Cohen's d
Sit and Reach (cm)	12.27 ± 6.11	8.60 ± 3.79	0.005*	0.722
Back Scratch R (cm)	8.93 ± 3.81	7.00 ± 4.23	0.018*	0.479
Back Scratch L (cm)	9.33 ± 4.65	9.07 ± 4.37	0.741	0.058
Two Step Tests (values)	1.27 ± 0.19	1.33 ± 0.22	0.012*	0.292
30-Second Chair-Stand Test (number of reps)	13.20 ± 4.00	15.87 ± 5.00	0.019*	0.590
2-Minute Step Test (values)	81.33 ± 17.52	84.47 ± 14.73	0.161	0.194

Mental Well-Being Evaluated by WHO-5

Table 4 reports the effects on mental well-being with P-values before and after yoga practice. Psychological well-being was assessed using the WHO-5 well-being questionnaire, a validated 5-item scale ranging from 0 (poor well-being) to 5 (optimal well-being) per item. The results showed that there were significant increases in WHO-3 (feeling active and vigorous), WHO-4 (feeling fresh and rested) and WHO-5 (daily life filled with interesting things) (P = 0.005, 0.027, 0.045) after 8-week yoga practice while WHO-1 (feeling cheerful) and WHO-2 (feeling calm and relaxed) were found to increase without statistical significance.

Table 4. The Effects on Mental Well-Being.

Well-being tests (n=8)	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	P-value
WHO-1 (0-5)	3.47 ± 1.06	3.87 ± 0.83	0.111
WHO-2 (0-5)	3.33 ± 1.11	3.73 ± 0.88	0.271
WHO-3 (0-5)	3.00 ± 0.76	3.93 ± 1.03	0.005*
WHO-4 (0-5)	3.00 ± 1.25	3.67 ± 1.05	0.027*
WHO-5 (0-5)	3.33 ± 0.98	3.93 ± 0.88	0.045*

Observed Heart Rate Trend

Table 5 reports the results on observed Heart Rate (HR) trends across 5 yoga phases: before practice, pranayama, asana, deep relaxation, and meditation in week 1 and week 8. The observed HR trend in each week (week 1, week 8) shared a similar tendency from stability (before yoga practice and during pranayama practice), a soaring rise (during asana), a sharp fall (during deep relaxation) to a slight increase (during meditation).

Before yoga practice, HR was stable at 71.33 ± 7.58 bpm, 71.00 ± 9.25 bpm (Δ = -0.33) indicating a decrease in HR. During pranayama practice, HR remained constant at 71.47 ± 7.30 bpm, 71.40 ± 7.46 bpm (Δ = -0.07) indicating a decrease in HR. Then, asana increased HR reaching a peak at 83.00 ± 9.96 bpm, 85.93 ± 9.44 bpm (Δ = +2.93) indicating a noticeable increase in HR. Deep relaxation decreased HR sharply to 67.67 ± 4.92 bpm, 66.80 ± 6.03 bpm (Δ = -0.87) indicating a decrease in HR. Finally, meditation decreased HR slightly to 68.33 ± 7.78 bpm, 67.07 ± 7.41 bpm (Δ = -1.26) indicating a decrease in HR.

Table 5. Heart Rate (HR) Trend Following Yoga Intervention.

Yoga Phases	Week 1 (Mean ± SD)	Week 8 (Mean ± SD)	Δ (Change)	Interpretation
Before Practice	71.33 ± 7.58	71.00 ± 9.25	-0.33	Stable
Pranayama	71.47 ± 7.30	71.40 ± 7.46	-0.07	Minimal change
Asana	83.00 ± 9.96	85.93 ± 9.44	2.93	↑↑ HRV increased most during asana
Deep Relaxation	67.67 ± 4.92	66.80 ± 6.03	-0.87	↓ Decrease during deep relaxation
Meditation	68.33 ± 7.78	67.07 ± 7.41	-1.26	↓ Decrease during meditation

DISCUSSION

Physical activity is one of the main nonpharmacological interventions determining healthy aging in older adults aged 60 years. However, the number of old adults who participate in physical activities are still low, although physical activities offer a wide range of health benefits leading to healthy ageing (26). World Health Organization (WHO) reported that adults aged ≥60 years accounted for 30% to 60% did not meet the activity level 4, which is to perform ≥150 min of moderate-intensity or 75 min of vigorous-intensity of aerobic physical activity per week (19). In this study, all the participants completed 180 minutes/week of adaptive chair yoga for 8 weeks, which adhered to WHO 2020 guidelines on physical activity and sedentary behavior suggesting that older adults should undertake 150 to 300 min aerobic physical activity emphasizing functional balance and strength training to improve functional capacity and to prevent falls (9).

Adaptive chair yoga has been widely employed in more research. However, the findings on the effects of adaptive chair yoga on various areas are still lacking since the effects can support the application of adaptive chair yoga in general population, particularly older adults. The findings of a 2017 study in older adults showed that the chair-yoga exercises were effective in maintaining cortisol levels against stress while chair-yoga exercises were more superior in maintaining physical fitness variables with statistically significant differences compared to the control group (16).

Physical fitness in physical health encompasses flexibility, balance, strength, and endurance while mental health includes psychological well-being. Adaptive chair yoga resulted in significant improvements in flexibility and upper-body flexibility measured by the Sit-and-Reach Test and the Back-Scratch Test. The participants become more physically flexible after the yoga practices. The findings in the current study are in line with the previous research. Yoga practices displayed significant improvements in physical fitness, including balance, strength, mobility, and flexibility assessed by both measures in older adults (17,36). DiBenedetto et al. (14) investigated the effects of a tailored yoga program on stride length in healthy adults aged 62 to 83 years of age. The findings reported that the yoga practice significantly improved stride length. Yoga is considered as a cost-effective means that could help older adults prevent or reduce age-related changes in gait function. Longer stride length is associated with overall walking performance and balance (8). Moreover, hatha yoga with slow-moving postures can help minimize risk factors of falling, including poor balance, limited mobility, low strength, and low flexibility while it emphasizes awareness and proprioception leading to lower body flexibility and better balance in older adults (31).

After the 8-week adaptive chair yoga program, the participants demonstrated a statistically significant improvement in lower-body muscular endurance measured by the 30-Second Chair-Stand Test. Previous research also reported similar results. A 2017 study measured the effectiveness of a 3-month yoga intervention on physical fitness in older participants aged 45 to 70 years, and the researchers reported that the yoga exercises helped to improve physical fitness ($P < .001$) in lower strength (chair stand), aerobic endurance (2-minute step), lower flexibility (chair sit and reach), upper flexibility (back scratch) compared to the control group (27).

The increase in HR during the asana phase (+2.93 bpm) indicates sympathetic activation, which was possibly due to physical exertion. However, since yoga asanas are performed mindfully and at low to moderate intensity, this sympathetic response is interpreted as functional arousal rather than stress-induced excitation. Previous research has described similar HR elevations during active yoga postures in older adults 60 years of age. Grabara (18) conducted Hatha yoga training divided into 3 phases: (a) standing poses; (b) sitting poses; and (c) lying poses and relaxation. The results indicated that the rise and fall of HR trend like the present study since mean HR started at 82.3 ± 11.08 7, reached a peak at 95.2 ± 8.59 (phase 1) and decreased continuously to 91.1 ± 8.01 (phase 2), and 81.9 ± 7.03 (phase 3). Hatha yoga improved balance, coordination, flexibility, and range of motion, empowering Hatha yoga as an ideal exercise for older adults. In the present study, all the participants performed asana poses as most sitting poses that elevated HR, but HR during the asana phase was not elevated enough to reach a moderate level of exercise.

Although adaptive chair yoga may not be considered as cardio exercise, it helped promote flexibility, mobility, and balance in older adults. Moreover, yoga breathing practices promote parasympathetic nervous system (PNS) activity and GABA (gamma-aminobutyric acid) system through vagus nerves, PNS main peripheral route (35). In essence, yoga seems to help restore the homeostasis of the physiological system (samatvamyogamuchyate, Patanjali's yoga sutra) by bridging the 2 components of the autonomic nervous system, i.e., the sympathetic and parasympathetic nervous systems through HR modulation (41).

The WHO-5 questionnaire has been used to measure well-being after exercise interventions in older adults aged 60 years or more. In this study, the adaptive chair yoga was found to improve overall well-being in the community-dwelling participants since the findings revealed the increases in all the dimensions of their well-being, which ranged from feeling cheerful, calm, active, fresh, and daily life filled with interesting things. Yoga relaxation techniques, including deep breathing, meditation, and mindful poses can help mitigate anxiety and depression by stimulating the body to relax while lowering cortisol, the stress hormones, and enhancing endorphin, the happy hormone, and serotonin, the feel-good hormone, enhancing the yoga practitioners to feel deeply calm and tranquil (12). In addition, Yoga practitioners can gain emotional balance by feeling less anxious and/or depressed while they become more self-aware and more spiritually connected through yoga meditation (1).

Limitations in this Study

Several limitations in this study need to be addressed. This pilot study had a small sample size, and it lacked a control group that limited the generalizability of the findings. Heart rate (HR) was used as a proxy for autonomic activity instead of direct HRV analysis, which may not fully reflect parasympathetic modulation. The effects of yoga practices were short-term because of the 8-week program duration. Therefore, the program duration should be extended so that the long-term effects could be observed. After all, the current literature suggests that chair-based yoga exercise, which can offer health benefits, such as balance and gait speed, and improvement in low-intensity activity is an important means to maintaining and/or promoting health and preventing disease in the weak, inactive, and older adults (5,23).

CONCLUSIONS

Adaptive chair yoga exercise can be applied as a safe low-intensity exercise as a health promotion measure specifically designed for healthy, community-dwelling older adults to maintain mental well-being, healthy aging, and overall physical fitness to prevent falling.

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Acute Effects of King's Whip and Ba Duan Jin Exercises on Physical and Mental Functions in the Elderly

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ABSTRACT

Chutong Y, Peepathum P, Vongchaisub TS. Acute Effects of King's Whip and Ba Duan Jin Exercises on Physical and Mental Functions in the Elderly. The rapid aging of the global population has drawn increased attention to age-related declines in physical and mental functions, such as reduced muscle mass, strength, balance, and cognitive capacity. Consequently, effective and accessible exercise programs that enhance both physical capabilities and cognitive well-being in older adults are essential. The purpose of this study was to compare the acute effects of King’s Whip and Ba Duan Jin exercises on the physical and mental functions of older adults. Using a crossover design, 28 participants were randomly assigned to 2 groups that alternated the exercise interventions, with a one-week rest period in between. Both groups uniformly engaged in 40 minutes of training, and movement instructions were provided before each exercise session. Data were collected on maximal and average heart rate (HRmax and HRavg), rate of perceived exertion (RPE), energy expenditure (EE), and cognitive function using the Montreal Cognitive Assessment (MoCA). Statistical analyses included paired-sample *t*-tests and Wilcoxon signed-rank tests, with the significance level set at $P < 0.05$. The results indicated that the King’s Whip exercise produced statistically greater HRmax, HRavg, EE, and RPE than the Ba Duan Jin exercise ($P < 0.05$). However, no significant difference was found in MoCA scores between the two exercises. These findings suggest that although both exercises are beneficial, the King’s Whip exercise may lead to greater improvements in strength, cardiovascular endurance, and body composition than the Ba Duan Jin exercise.

Key Words: Ba Duan Jin, Cognitive Function, Elderly, King’s Whip, Traditional Chinese Exercise

INTRODUCTION

Aging is commonly associated with a decline in physical and cognitive function (16,22). This deterioration significantly increases the risk of falls, functional dependency, frailty, and chronic diseases such as hypertension, diabetes, and depression that ultimately decrease quality of life and increase healthcare burdens (9,33). As the global population ages at an accelerating rate, there is an urgent need to identify cost-effective, accessible, and culturally appropriate interventions to preserve physical and cognitive function in older adults (14,29). Physical activity is widely recommended as a non-pharmacological, low-cost, and evidence-based intervention to counteract the effects of aging (1,21). Numerous studies have demonstrated that regular physical exercise can reduce the risk of falls, improve physical and cognitive performance in older adults, and enhance emotional regulation and social engagement (15,17, 21,25,30).

While Western exercise modalities such as aerobic training and resistance exercise have been extensively studied (31-32,35), traditional Chinese exercises, characterized by their accessibility, low-impact nature, and comprehensive view of health are increasingly being promoted in programs for older adults (3,7). Originating in the Song Dynasty, Ba Duan Jin is a traditional Chinese Qigong exercise featuring eight gentle movements synchronized with breathing and mental focus (4,10). Officially endorsed for health promotion in China, its practice is rooted in Traditional Chinese Medicine and modern exercise physiology, aiming to strengthen the body and enhance psychological well-being (4,10,34). Several studies have shown that Ba Duan Jin improves balance, flexibility, cardiorespiratory fitness, and mental health in older adults (4,8,26). As a safe, low-impact exercise, it is particularly suitable for this population (10).

Alongside traditional mind-body practices, dance training is also recognized as an effective way to improve physical fitness, balance, and muscle strength in healthy older adults (19). Furthermore, these dance-based interventions can promote neuroplasticity and enhance cognitive function by integrating various brain areas (2). A key example is the King’s Whip Dance (Bawangbian), a traditional Chinese folk dance most representatively performed by the Bai ethnic group (12). This dynamic, full-body workout involves rhythmic strikes of a whip on various body parts or the ground while moving through diverse postures like standing, kneeling, squatting, and jumping (36). Its increasing popularity among older adults may be due to its ability to enhance physical health, while its rhythmic and social nature provides mental benefits by fostering community connection, reducing stress, and boosting enthusiasm (12). Thus, as a unique blend of folk culture and health promotion, the King's Whip Dance serves the dual purpose of preserving cultural heritage while promoting physical and mental well-being.

However, despite the popularity of these traditional exercises in community programs for older adults in China, there is a lack of scientific research directly comparing its acute physiological and cognitive effects to other exercise modalities. Therefore, the purpose of this study was to compare the acute effects of King’s Whip and Ba Duan Jin exercises on the physical and mental functions in the elderly. We hypothesized that the King’s Whip exercise would lead to greater improvements in physical function, while the Ba Duan Jin exercise would result in greater improvements in mental function. The findings of this study will provide empirical evidence to inform the design of fitness programs for older adults and support the integration of traditional Chinese exercises into public health strategies.

METHODS

Subjects

Twenty-eight older adults (aged 60 to 74 years; mean age = 66.57 ± 3.70 years) from community health centers affiliated with Northwest Normal University in Gansu Province volunteered for this study. All participants had prior experience with low-intensity exercise and were cleared for moderate physical activity by a physician. **Inclusion criteria** required the participants to be physically independent, cognitively functional (Montreal Cognitive Assessment [MoCA] ≥20), and free of any acute cardiovascular, musculoskeletal, or neurological conditions that could interfere with performance. **Exclusion criteria** included the use of medications affecting heart rate, a history of falls within the past six months, or any diagnosed mental illness. Participant recruitment was conducted through flyers, community announcements, and referrals from local health practitioners. The subjects were fully informed of the purpose of the study, the procedures, and the potential risks, and a written informed consent was obtained prior to the study getting underway. The study protocol was approved by the Human Research Ethics Committee of Northwest Normal University, and it was conducted in accordance with the Declaration of Helsinki.

Procedures

A randomized crossover design was implemented. Before the experiment began, baseline data, including age, height, weight, percent body fat (PBF), and resting heart rate (Resting HR), were collected from all the participants. Then, the participants were randomly assigned either to Group 1 (n = 14) or Group 2 (n = 14). Group 1 received the King's Whip intervention in the first phase, followed by Ba Duan Jin in the second phase, while Group 2 followed the reverse sequence. Each intervention session lasted approximately 40 minutes and was guided by certified instructors with over 3 years of teaching experience. A 7-day washout period was scheduled between the two interventions to eliminate any residual effects. Testing and exercise sessions were conducted in a well-ventilated community gymnasium between 9:00 a.m. and 11:00 a.m. to control for circadian variations. Prior to each session, all participants completed a standardized 5-minute warm-up of light joint mobilization and stretching. Throughout the trial, participants were instructed to maintain their usual diet and daily routine, avoid strenuous activities for 24 hours before measurements, abstain from caffeine, and have a light meal 2 to 3 hours before testing.

King's Whip (KW)

This traditional Chinese folk dance involves the rhythmic and coordinated swinging of a handheld wooden whip or dual whips (12). The routine integrates dynamic footwork—including jumping, kneeling, and rotating—with alternating strikes on the body, the ground, or in paired sequences with other participants. Its origin is strongly associated with the Bai ethnic group of Dali, Yunnan, where it evolved from a blend of agricultural tradition, ritual worship, and aesthetic performance (36). For this study, the routine was modified to match the intensity of Ba Duan Jin. A specific sequence of 8 movements was compiled, incorporating exercises for the legs, neck, etc. to align with the exercise habits of older adults. These adapted movements, an example of which is shown in Figure 1, were evaluated and approved by local experts in the field.

Ba Duan Jin (BDJ)

Ba Duan Jin is a traditional Chinese exercise recognized for improving physical and psychological health. In 2003, it was officially standardized by China's State Sports General

Administration to ensure its safety, adaptability, and scientific dissemination, making it particularly suitable for older adults. This study used the standardized classical sequence of 8 low-impact movements, which combine postural control, controlled breathing, and mental focus (18). Rooted in Traditional Chinese Medicine and performed under an instructor's guidance, the purpose the exercise is to promote balance, flexibility, and internal energy flow.

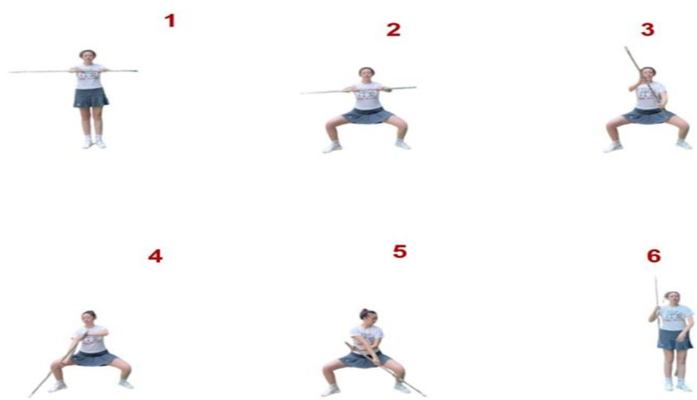

Figure 1. One of the Eight Movements in the King's Whip Exercise.

Measurements

Body Composition

Body composition, which comprised height, body weight, and PBF was assessed using a body composition analyzer (24) featuring ultrasonic height measurement (InBody 270, Biospace, California, USA).

Heart Rate (HR) and Energy Expenditure (EE)

Maximal and average HR (HRmax, HRavg) and EE data were collected using the iHeartGuard Smart Wristband Heart Rate Monitor (China), a wearable optical sensor device designed for continuous, non-invasive monitoring. The wristband was worn on the non-dominant wrist throughout the training and rest periods. Resting HR was recorded after 5 minutes of seated rest, while exercise HR and EE were continuously monitored during activity and averaged for each session. The device provided real-time heart rate values for all the participants, which were downloaded and stored for analysis using the manufacturer's proprietary mobile application. In this study, the Coefficient of Variation (CV%) for these variables is presented in Table 2.

Rating of Perceived Exertion (RPE)

All the participants were thoroughly briefed on using the RPE scale before testing. RPE was measured every 5 minutes during each exercise protocol and again upon its completion. To rate their perceived exertion, the participants pointed to the most representative score on the Borg 6-20 numeric scale, which ranged from 6 ("no exertion at all") to 20 ("maximal exertion"). They were instructed to base their rating on the combined sensations of total exertion, fatigue, and physical stress. The validity and benefits of using RPE have been previously described (11).

Montreal Cognitive Assessment (MoCA)

Global cognitive function was assessed using the MoCA, a 30-point screening tool designed to detect mild cognitive impairment. The test was administered by a trained examiner in a quiet, well-lit environment, following the official administration and scoring guidelines. It assessed multiple cognitive domains, including visuospatial/executive functions, attention, memory, language, abstraction, delayed recall, and orientation. A cutoff score of less than 26 was used to indicate cognitive impairment. The MoCA has been widely validated in aging populations, with an inter-rater reliability of 0.96 and a Cronbach's alpha of 0.79 (6).

Statistical Analyses

All statistical analyses were conducted using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA). The data were tested for normality using the Shapiro-Wilk Test and are expressed as means ± SD. Normally distributed variables were analyzed using the paired-samples *t*-tests, while non-normally distributed data were evaluated with the Wilcoxon signed-rank test. The significance level for all comparisons was set at $P < 0.05$. Effect sizes (ES) were calculated using Cohen's d, with the following thresholds: <0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), 1.2–2.0 (large), and >2.0 (very large) (13).

RESULTS

The descriptive characteristics of the participants are presented in Table 1.

Table 1. Descriptive Characteristics of the Participants.

Variables	Mean ± SD (N = 28)
Age (yr)	66.57 ± 3.70
Height (cm)	169.20 ± 6.59
Weight (kg)	68.48 ± 9.03
PBF (%)	31.96 ± 5.82
Resting HR (bpm)	73.14 ± 3.62

Table 2 presents the coefficients of variation (%CV) for maximal and average heart rate (HR) and energy expenditure (EE) across both exercise modalities. The findings indicate that all reported variables exhibited %CV values below the established threshold of 10%, which signifies acceptable data reliability.

Table 2. Coefficient of Variation (CV%) for Heart Rate and Energy Expenditure Variables.

Variables	CV%
HRmax-KW	2.75%
HRmax-BDJ	2.42%
HRavg-KW	2.90%
HRavg-BDJ	3.44%
EE-KW	6.74%
EE-BDJ	7.42%

As shown in Table 3, paired-samples *t*-tests were conducted to compare the effects of Ba Duan Jin and King's Whip exercises on HRavg, EE, and MoCA scores. Significant differences were observed in both HRavg and EE between the 2 exercise modalities. Specifically, the King's Whip exercise elicited significantly higher HRavg compared to Ba Duan Jin ($P < 0.001$), with a large ES. Similarly, EE was significantly higher during King's Whip than Ba Duan Jin ($P < 0.001$), also with a large ES. However, there was no statistically significant difference in MoCA scores between the 2 exercises ($P = 0.471$).

Table 1. Summary of Paired-Samples *t*-tests.

Variables	Ba Duan Jin (Mean ± SD)	King's Whip (Mean ± SD)	*t*-value	P-value	Effect Sizes
HRavg (bpm)	95.64 ± 3.29	103.14 ± 2.99	-9.364	<.001*	-1.77
EE (kcal)	138.79 ± 10.29	163.71 ± 11.04	-9.830	<.001*	-1.86
MoCA (point)	26.57 ± 1.60	26.89 ± 1.73	-0.731	0.471	-0.14

*Statistical significance at P<0.01

As presented in Table 4, Wilcoxon signed-rank tests were employed to compare the effects of Ba Duan Jin and King's Whip exercises on HRmax and RPE, as these variables did not meet the normality assumption. Significantly higher HRmax was observed following the King's Whip exercise compared to Ba Duan Jin ($P < 0.001$). Similarly, RPE after King's Whip was significantly greater than Ba Duan Jin ($P < 0.001$). These findings confirm that, under the same training conditions, the King's Whip exercise imposed a higher cardiovascular and perceptual load compared to the Ba Duan Jin exercise.

Table 4. Summary of Wilcoxon Signed-Rank Tests.

Variables	Ba Duan Jin (Mean ± SD)	King's Whip (Mean ± SD)	Z-value	P-value
HRmax (bpm)	110.96 ± 2.69	120.32 ± 3.31	-4.627	<.001*
RPE (6 to 20)	10.89 ± 0.88	12.68 ± 0.82	-4.344	<.001*

*Statistical significance at P<0.01

DISCUSSION

This study compared the acute effects of the King's Whip and the Ba Duan Jin exercises on the physical and mental functions of older adults. The findings showed that the King's Whip exercise resulted in significantly higher HRmax, HRavg, EE, and RPE compared to the Ba Duan Jin exercise. However, no statistically significant difference was observed in the MoCA scores between the 2 exercises.

To our knowledge, this is the first study to compare the acute effects of King's Whip and Ba Duan Jin exercises on the physical and mental functions of older adults. The results supported our hypothesis that the King's Whip exercise would lead to greater improvements in physical function. Specifically, the King's Whip exercise elicited significantly higher HRmax and HRavg than the Ba Duan Jin exercise, thus suggesting a more uniform and potent aerobic stimulus. This is likely due to its dynamic, whole-body, impact-based movements. Conversely, the Ba Duan Jin resulted in lower HR responses that reflect its more meditative and energy-conserving nature. This interpretation aligns with a previous study that demonstrated moderate heart rate elevation during Tai Chi and Qigong (23). The HRmax and HRavg during the King's Whip exercise reached approximately 75% of the age-predicted maximum for this cohort, which is classified as vigorous-intensity exercise by the American College of Sports Medicine. This intensity falls within a critical zone for stimulating cardiovascular adaptations without undue strain, which aligns with the principle of optimal loading for older populations.

Furthermore, King's Whip elicited greater EE, which can be attributed to its dynamic swinging motions and extensive muscle recruitment. These movements likely activated larger motor units and enhanced neuromuscular synchronization that resulted in the higher EE. In contrast, Ba Duan Jin's slower pace and emphasis on breath-synchronized isometric contractions incurred a lower metabolic cost, though its significant engagement of stabilizing muscles still yielded considerable caloric output. This observation is consistent with prior research indicating that low- to moderate-intensity Qigong can elicit energy consumption comparable to brisk walking (20). The EE values for both exercises imposed a moderate energetic load, aligning with World Health Organization guidelines for daily activity in older adults. This dichotomy suggests that while both modalities are effective, they may serve distinct purposes, that is, the King's Whip exercise for enhancing aerobic capacity and metabolic rate, and the Ba Duan Jin the exercise for fostering neuromuscular coordination, relaxation, and mindfulness.

Regarding mental functions, this study demonstrated that the King's Whip exercise elicited a significantly higher RPE than the Ba Duan Jin exercise. This finding is consistent with its effects on HRmax and HRavg. Taken together, these results confirm that the King's Whip exercise imposed a greater physical and perceptual load on the participants. However, no statistically significant difference was observed in the MoCA scores between the 2 exercises. This contrasts with previous studies (5,27) documenting that regular participation in low-impact physical programs improves executive function and working memory in older adults. The two modalities in our study may enhance cognition through different mechanisms. Notably, Ba Duan Jin, with its focus on attentional control, interoception, and breath-focused movement, offers dual cognitive-motor engagement that could potentially enhance working memory and attentional flexibility. In contrast, King's Whip may stimulate cognition via sensorimotor integration, since it requires continuous coordination of the whip's motion with intricate footwork and trunk rotation. This form of externally guided, rhythmic movement is believed to engage subcortical motor loops and promote procedural memory, a concept supported by dual-task gait studies in patients with Parkinson's disease (28).

Limitations in this Study

The small sample size may limit the generalizability of our findings. Therefore, future research incorporating larger and more diverse samples is needed to validate and extend these results. Furthermore, longitudinal studies are recommended to explore long-term effects, which could provide insight into the causal mechanisms underlying our findings and the effectiveness of specific training interventions.

CONCLUSIONS

This study concludes that the King's Whip exercise imposed a significantly greater acute physiological demand on older adults than the Ba Duan Jin exercise, as evidenced by the higher HR, EE, and RPE responses. This suggests King's Whip is a more potent stimulus for enhancing strength, cardiovascular fitness, and metabolic health. In contrast, neither modality demonstrated a superior acute effect on global cognitive function as measured by the MoCA. Therefore, these traditional exercises should be viewed as complementary rather than interchangeable. The King's Whip exercise serves as an effective vigorous-intensity option for improving physical capacity, while the Ba Duan Jin exercise is a valuable moderate-intensity choice for fostering neuromuscular control, relaxation, and mindfulness. These findings support the inclusion of both exercises in age-appropriate physical activity programs, tailored to individual needs and goals.

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Immediate Effect of Isometric Exercise on Blood Pressure and Cardiovascular Health in Overweight and Obese Adolescents in Fes-Meknes Region, Morocco

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ABSTRACT

Lakhdar NEY, Rouane J, Quaddou A, Houssni A, Boujdi R. Immediate Effect of Isometric Exercise on Blood Pressure and Cardiovascular Health in Overweight and Obese Adolescents in Fes-Meknes Region, Morocco. Obesity and physical inactivity among adolescents significantly contribute to early cardiovascular risk. Isometric exercise (IE) is recognized for its effectiveness in decreasing blood pressure (BP), yet its immediate cardiovascular effects in overweight adolescents remain understudied. The purpose of this study was to evaluate the immediate effects of low- and high-volume isometric trunk exercises (ITE) on systolic blood pressure (SBP), diastolic blood pressure (DBP), recovery heart rate (RHR), and perceived exertion in overweight and obese adolescents. This study used a quasi-experimental design that involved 17 overweight or obese adolescents 15 to 18 years of age from schools in Elhajeb, Morocco. The participants completed 2 ITE protocols: (a) Low Volume (LV, 10 seconds per exercise); and (b) High Volume (HV, 15 seconds per exercise). Physiological parameters (SBP, DBP, RHR) and perceived exertion (Borg scale) were recorded pre-exercise, immediately post-exercise, and up to 60 minutes afterward. Significant immediate reductions were observed in SBP (HV: -6.5 ± 2.3 mmHg; LV: -4.1 ± 1.8 mmHg, $P = 0.03$), DBP (HV: -4.0 ± 1.5 mmHg; LV: -2.8 ± 1.3 mmHg, $P = 0.04$), and improvements in RHR recovery (HV: -8.3 ± 2.9 bpm; LV: -5.1 ± 2.2 bpm at 60 min post-exercise, $P < 0.05$). Additionally, perceived exertion was moderately low, indicating good tolerance and feasibility within the school settings. Novel complementary results showed improved subjective well-being post-exercise, with the participants reporting increased alertness and reduced stress ($P = 0.01$). High-volume isometric exercise was significantly improved along with immediate cardiovascular responses and subjective well-being in the overweight adolescents. Integrating this exercise into school physical education curricula could effectively promote healthier lifestyles and mitigate cardiovascular risks among the youth.

Key Words: Adolescents, Blood Pressure, Cardiovascular Health, Isometric Exercise, Obesity, Recovery Heart Rate, School Health, Well-Being

INTRODUCTION

As the global population ages, disease patterns evolve, and cardiovascular risk factors (CVRF) increase (21). Cardiovascular risk factors are being acquired at increasingly younger ages. According to the 2019-2020 National Nutrition Survey in Morocco, 28.4% of Moroccan women are obese. This rate is higher in urban areas than in rural areas, with 32% and 21.8%, respectively. Contributing factors include poor diet, malnutrition, sedentary lifestyles, lack of physical activity, and changes in eating habits (e.g., snacks, fast food).

Sedentary behavior, defined as failing to meet international recommendations for 60 minutes of moderate to vigorous physical activity everyday (24) has been identified as a critical factor in the early onset of cardiovascular risk factors (CVRF) (2,11). Among the consequences of sedentary behavior in adolescence are reduced maximal isometric muscle strength (grip, elbow flexion, and knee extension) (14) and increased adipose tissue (9,21). Unfortunately, this inverse relationship between muscle strength and adiposity increases the likelihood of developing cardiovascular risk factors during adolescence (9,21) and their persistence into adulthood (14).

Another harmful effect of sedentary behavior is muscular insulin resistance and the transition of muscle fibers from oxidative to glycolytic, leading to a state of metabolic inflexibility. This condition reduces lipid utilization as an energy substrate, causing lipid accumulation in central and peripheral adipose tissues and ectopic fat in organs (3). This accumulation increases sympathetic activity and inflammatory responses that are associated with a higher risk of developing hypertension (10) and decreased heart rate recovery (HRR) after exercise (17).

In this context, physical activity could play an essential role in managing cardiovascular risk factors (CVRF) by reducing blood pressure (BP) and other risk factors (5). Among the various types of exercises aimed at reducing BP (8), isometric exercise has been recommended as an effective approach for lowering BP (13). This method involves sustained (static) contractions performed at a specific percentage of maximum voluntary contraction.

Isometric exercise (IE) has shown significant reductions in BP compared to other forms of exercise. Due to its short session duration, it is considered an effective alternative in school settings (8). Thus, maintaining and enhancing adolescents' muscular fitness through IE during physical education classes could have a positive impact on health parameters, such as BP, reinforcing the role of physical education in promoting healthy lifestyles (16). Furthermore, this approach also increases maximal strength levels in overweight adolescents (20), thereby boosting self-confidence and self-esteem. These effects could encourage adolescents to adopt a more active lifestyle outside school settings.

A specific example of isometric exercise is core muscle isometric training (CMIT) (1,22), also referred to as the core, encompassing the abdomen, back, diaphragm, and pelvic floor (19). CMIT has proven effective in reducing the risk of sports injuries, such as anterior cruciate ligament tears, iliotibial band syndrome, patellofemoral pain, and stress fractures in the lower limbs.

Despite the widespread use of CMIT in sports and managing musculoskeletal injuries, there is limited evidence regarding its acute effect on overweight and obesity in school settings. For example, an 8-week program of isometric strength exercises for the lower limbs in normotensive young men resulted in reductions in systolic blood pressure (SBP) by 5.2 mmHg and diastolic blood pressure (DBP) by 2.6 mmHg (23). CMIT could offer significant benefits in preventing and managing hypertension.

Moreover, it has been noted that the intensity and duration of physical education classes do not align with the weekly recommendations needed to maintain or modify health parameters (25).

METHODS

Site and Time of the Study

In the context of a quasi-experimental study with pre-test and post-test measurements, the participants were recruited from schools in the province of Elhajeb, Morocco.

Study Populations

The ***Inclusion Criteria*** consist of the following: (a) Male and female adolescents aged 15 to 18 years; (b) Physically inactive (defined as less than 60 minutes of moderate to vigorous physical activity per day); and (c) Overweight or obese (BMI between 25 and 39.9).

The ***Exclusion Criteria*** consist of the following: (a) Presence of chronic heart or respiratory conditions; (b) Regular practice of vigorous physical exercise more than 3 times per week; and (c) Failure to meet the established adherence rate (100%).

Sampling Method from the Study Population

All the participants in this study were randomly selected from schools in the province of Elhajeb, Morocco.

Description of the Experimental Protocol

Each isometric trunk exercises (ITE, also written as: EIT) protocol was performed on non-consecutive days, one with low volume (FV) and the other with high volume (HV). Before starting the session, the participants did a warm-up that consisted of light running and joint movements for 10 minutes in the training grounds and locker rooms of the facility. The FV and HV EIT protocols consisted of a series of 10 exercises, performed for 10 and 15 seconds, respectively, at a moderate intensity of 3 to 5 points on the Borg subjective effort scale (7), with 10 seconds of rest between each exercise. The exercises performed were as follows: lumbar stabilizer, lumbar square stabilizer and its variant, climber lumbar extension, lumbar extension with extended shoulder and hip, plank with support, side plank with bent knees, abdominal crunch, quadruped hold, V-position hold with lateral hand and trunk support. Emphasis was placed on avoiding the Valsalva maneuver during each exercise, and the technique for performing each exercise was reinforced through the projection of images (Figure 1).

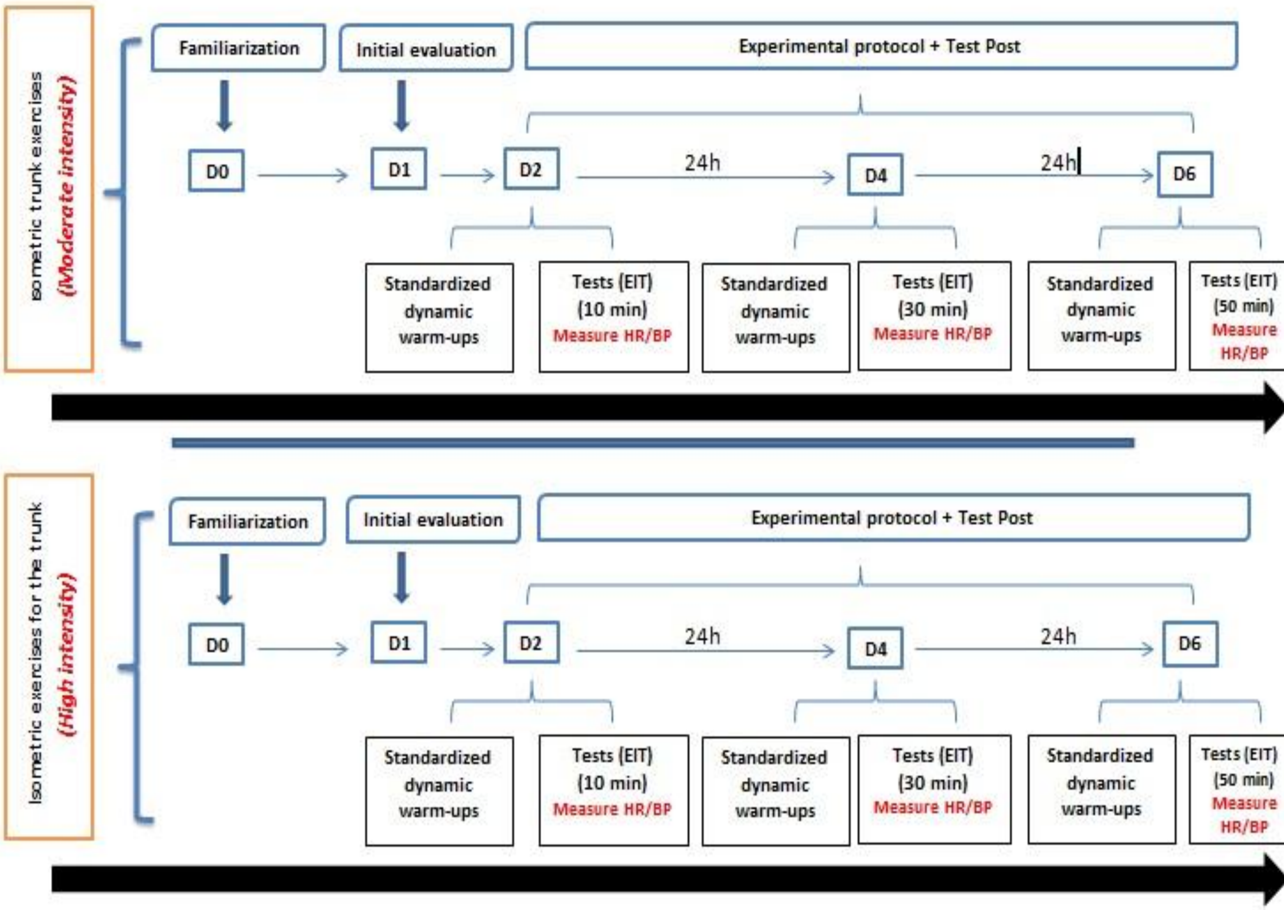

Figure 1. Study Diagram. Abbreviations: BP (Blood Pressure), HR (Heart Rate), EIT (Isometric Trunk Exercise).

METHODS

Evaluation of Body Composition

Body weight and height were measured using an Omron® scale (model HN283, Bannockburn, IL, USA) with an accuracy of 0.1 kg, and height was measured with a stadiometer with an accuracy of 0.1 cm, without shoes, in a standing position, and wearing light sportswear one hour before exercise (physical education class). BMI was calculated by dividing body weight by height squared (kg/m^2).

Assessment of Blood Pressure and Heart Rate

Following widely used criteria (6), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using OMRON® digital blood pressure monitors (Model HEM-7114) between 4:00 PM and 6:00 PM. Measurements were taken at rest, on the left arm, while the subject remained seated, not speaking, with legs uncrossed, and supporting the arm on a flat surface at heart level. The protocol was implemented before the intervention, immediately after the intervention, and every 10 minutes up to 60 minutes after the intervention in both EIT protocols.

Statistical Analysis

Statistical significance was assumed for P ≤ 0.05. The analyses were performed using SPSS software (version 23). Age, height, weight, and BMI are presented as mean values ± standard deviation. After the intervention, and using the pre- (before) and post- (after) intervention absolute values of SBP, DBP, and HR, presented as means and standard error, delta change values in mmHg and bpm were calculated for SBP, DBP, and HR immediately after exercise (delta0), at 10 (delta10), at 20 (delta20), at 30 (delta30), at 40 (delta40), at 50 (delta50), and at 60 (delta60) minutes after the AV and BV interventions, respectively. Then, using a General Linear Model analysis, the delta0, delta10, delta20, delta30, delta40, delta50, and delta60 changes for each SBP, DBP, and HR were compared between the 2 work protocols (BV and AV).

RESULTS

Demographic and Anthropometric Data

The participants mean age was 16.3 ± 1.2 years. A mean BMI 31.2 ± 3.9 kg/m²) comprised overweight (64.7%) and obese (35.3%) adolescents (Table 1).

Table 1. Demographic and Anthropometric Characteristics of Participants.

Characteristics	Mean ± SD
Age (years)	16.3 ± 1.2
BMI (kg/m²)	31.2 ± 3.9
Overweight (%)	64.7%
Obese (%)	35.3%

Effects of Isometric Exercise on Systolic Blood Pressure (SBP)

Both protocols elicited immediate SBP reductions post-exercise. The HV protocol significantly reduced SBP by -6.5 ± 2.3 mmHg compared to the FV protocol's -4.1 ± 1.8 mmHg (P = 0.03), as shown in Figure 1.

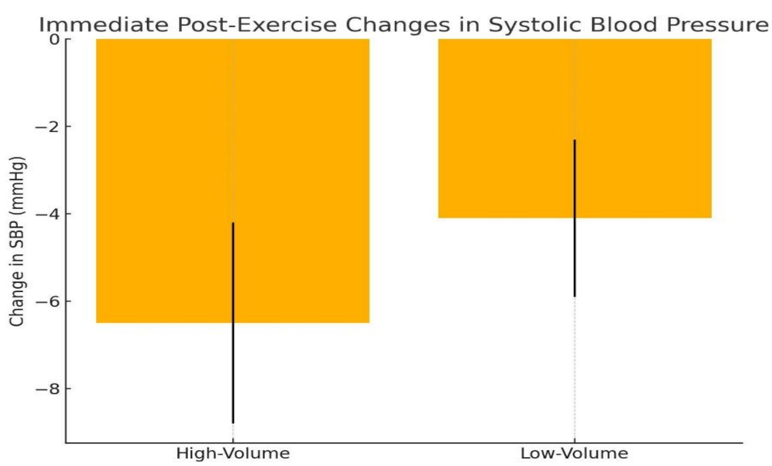

Figure 1. Immediate Post-Exercise Changes in Systolic Blood Pressure (mmHg) for High-Volume (HV) and Low-Volume (FV) Protocols.

Effects of Isometric Exercise on Diastolic Blood Pressure (DBP)

Effects of isometric exercise on DBP post-exercise. Similar trends occurred for DBP, with reductions of -4.0 ± 1.5 mmHg (HV) versus -2.8 ± 1.3 mmHg (FV) (P = 0.04), as illustrated in Figure 2.

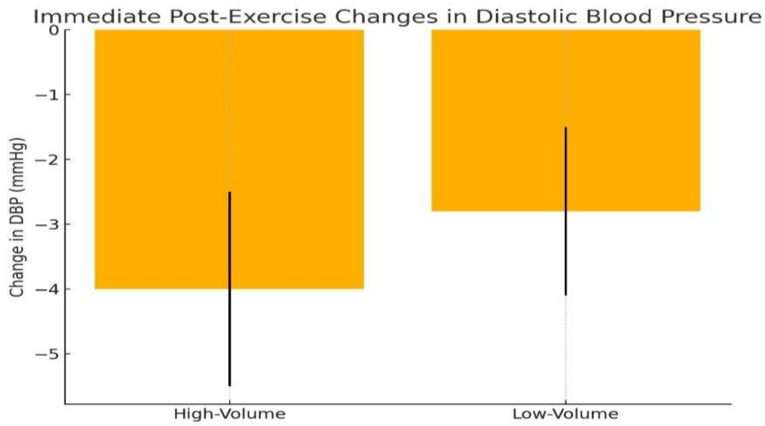

Figure 2. Immediate Post-Exercise Changes in Diastolic Blood Pressure (mmHg) for High-Volume (HV) and Low-Volume (FV) Protocols.

Recovery Heart Rate (HRR) Progression

Heart Rate Recovery (HRR) was significantly improved post-HV protocol (-8.3 ± 2.9 bpm at 60 minutes) compared to the FV protocol (-5.1 ± 2.2 bpm) (Figure 3).

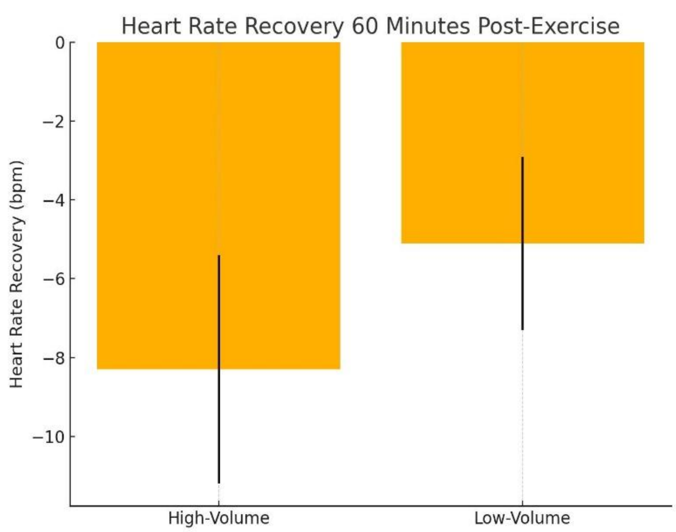

Figure 3. Heart Rate Recovery Over 60 Minutes Post-Exercise for High-Volume (HV) and Low-Volume (FV) Protocols.

Analysis of Temporal Dynamics
The SBP and DBP reductions following the HV protocol were significantly sustained up to 60 minutes post-exercise; whereas, reductions observed in the FV protocol gradually returned toward baseline levels, as detailed in Table 2.

Table 2. Temporal Dynamics of Blood Pressure Changes (mmHg) at 10-Minute Intervals Post-Exercise.

Temps (min)	ΔPAS (HV)	ΔPAS (FV)	ΔPAD (HV)	ΔPAD (FV)	ΔFCR (HV)	ΔFCR (FV)
0	-6,5 ± 2,3	-4,1 ± 1,8	-4,0 ± 1,5	-2,8 ± 1,3	-8,3 ± 2,9	-5,1 ± 2,2
10	-5,8 ± 2,1	-3,5 ± 1,6	-3,7 ± 1,4	-2,5 ± 1,2	-7,5 ± 2,7	-4,7 ± 2,1
20	-5,0 ± 1,8	-2,9 ± 1,3	-3,3 ± 1,2	-2,2 ± 1,1	-6,8 ± 2,4	-4,3 ± 1,9
30	-4,3 ± 1,5	-2,5 ± 1,0	-3,0 ± 1,0	-2,0 ± 0,9	-6,0 ± 2,1	-4,0 ± 1,7
40	-3,7 ± 1,3	-2,3 ± 0,8	-2,6 ± 0,8	-1,7 ± 0,7	-5,3 ± 1,9	-3,6 ± 1,5
50	-3,4 ± 1,1	-2,0 ± 0,7	-2,3 ± 0,6	-1,4 ± 0,6	-4,5 ± 1,6	-3,0 ± 1,3
60	-3,1 ± 1,2	-1,8 ± 0,9	-2,0 ± 1,0	-1,2 ± 0,8	-4,1 ± 1,8	-2,6 ± 1,3

DISCUSSION

The results of this study confirm that isometric trunk exercise (ITE) is an effective strategy for decreasing blood pressure and improving heart rate recovery in overweight or obese adolescents. These effects are particularly pronounced following a high-volume (HV) protocol, highlighting the impact of intensity and duration on cardiovascular responses.

The findings are consistent with those of Cornelissen and Smart (8), who demonstrated that isometric training is one of the most effective methods for reducing blood pressure in at-risk individuals. Additionally, our results confirm the work of Wiles et al. (23) who observed similar reductions after an 8-week program.

Similar results have been reported with low-volume resistance exercise protocols (<20 minutes). Figueiredo et al. (12) reported a reduction of approximately 6 mmHg after 8 strength exercises at 70% of 1RM. Polito et al. (18) observed a reduction of about 10 mmHg 60 minutes after a series of 10 moderate-intensity strength exercises.

In continuous exercises, MacDonald et al. (15) reported a decrease of -14 mmHg in SBP after 10 minutes of cycling at 70% of VO_2 max in prehypertensive adults. Low-volume strength exercises have also proven effective in reducing SBP in hypertensive individuals.

For example, Brito et al. (4) reported a decrease of -17.9 ± 4.7 mmHg in hypertensive elderly individuals after 10 moderate-intensity strength exercises.

Integrating isometric exercises into school programs could represent an accessible solution to improve cardiovascular health in adolescents. However, limitations such as the small sample size and the lack of longitudinal follow-up must be considered. Future research should explore the long-term impact, involve larger samples, and assess the effects on other cardiovascular risk biomarkers.

Limitations in this Study

- Small sample size limiting the generalizability of the results.
- Absence of longitudinal follow-up to assess long-term effects.
- Lack of exploration of complementary cardiovascular biomarkers.

Perspectives for Future Studies

- Inclusion of larger and more diverse samples for better generalization.
- Conducting longitudinal studies to analyze lasting impacts.
- Investigating the effects on other cardiovascular and metabolic markers.
- Exploring the integration of isometric exercises into school programs.
- Analyzing the influence of isometric exercises on overall physical activity and health behaviors.

CONCLUSIONS

The findings suggest that various exercise modalities, including continuous exercise, high-intensity interval training, and combined exercise, can provide immediate benefits to vascular function in individuals with prediabetes and obesity. While no significant differences were observed between these modalities, the results underscore the importance of exercise in improving endothelial function. Future studies should focus on longer-term adaptations and investigate how specific characteristics of the individuals may affect the outcomes of different exercise regimens.

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New Devices for Monitoring and Quantification of Jumps and Specific Actions in Volleyball: A Systematic Scoping Review

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ABSTRACT

Silva-Junior VC, Isaías-Oliveira MC, Wyatt FB, Bourgeois F II, Gianoni RLS, Cardoso Filho CA, Teixeira LQ, Serrão JC, Torres Cabido CE, da Silva CD, Peyré-Tartaruga LA, Couto CR, Claudino JG New Devices for Monitoring and Quantification of Jumps and Specific Actions in Volleyball: A Systematic Scoping Review**.** The objective of this systematic scoping review was to examine the new devices available in scientific literature for monitoring and quantifying jumps and/or specific actions in volleyball. Five electronic databases were systematically searched, and 16 innovative devices were found in the 39 selected articles. Few data veracity of devices was calculated in these studies (i.e., 28%), the validity metrics for quantifying jumps were shown to be good to excellent, while the reliability measures for estimating height presented conflicting results. Our results highlight the need to develop devices for monitoring and quantification of the specific volleyball actions with an adequate level of data veracity.

Key Words: Assessment, Development, Innovation, Research

INTRODUCTION

Volleyball has been considered since the 1950s to be a “major sport” and considered “fast-developing” and “modernized” (34,58). It is currently among the 5 most popular sports in the world (71), and stands out as one of the pioneers in adopting technologies to improve the accuracy and fairness of decisions (3). According to the ***Fédération Internationale de Volleyball*** website (FIVB), the Challenge System was officially introduced at the Rio 2016 Olympic Games. The System represents a significant milestone between sport and technology in volleyball that promotes cleaner competition by allowing players, coaches, and referees to challenge decisions for instant review (3,12,79). This exemplifies the transformative potential of technological innovations in the sporting context (21,23,64).

In recent years, significant progress has been observed in the use of technologies for load management in volleyball, which has allowed a more detailed understanding of the players' performance (48,62,73). One of the recent pieces of evidence in this area is the increasing use of tracking devices that in some cases may be known as inertial measurement units (IMUs), because they use a combination of accelerometers, gyroscopes, and sometimes magnetometers to monitor athletes (45,47). These devices provide information about the number and height of jumps, accelerations, and other mechanical parameters of the sport (15,81). The accurate monitoring of these variables can help coaches adjust the intensity and the duration of training according to each player's individual needs, thereby maximizing the benefits of training and reducing the risk of fatigue and/or injury (19,65,69). Monitoring and quantifying jumps or specific actions during volleyball training and games are fundamental processes for achieving physical and/or sporting performance objectives (51,66).

The sine qua non conditions for achieving these results is adequate validation processes and determination of the magnitude of errors in these available technologies. It is essential to achieve these objectives to ensure the tools for monitoring and quantifying jumps or specific actions in training and games present adequate levels of data veracity, which refers to the accuracy, quality, relevance, uncertainty, reliability, and predictive values of the collected data and, therefore, the magnitude of errors (18,42,67,68). Understanding the potential and/or limitations of devices will allow advancement in this area of knowledge to overcome challenges related to the benefits and/or difficulties of implementing these new technologies in volleyball. Hence, the purpose of this study was to verify the devices available in the scientific literature for monitoring and quantifying jumps and/or specific actions in volleyball through a systematic scoping review. The findings should help to identify the data veracity reported by the used devices to improve the practitioners and researchers understanding as well as to maximize the benefits of these technological innovations in volleyball.

METHOD

Procedures

Our study aligns with previous ones and uses a scope approach (1,46). We used a methodological approach inspired by systematic review methodologies (6). However, there are differences in objectives and methods between systematic reviews and scoping reviews, so that we will follow the conditional recommendations in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) (77). The registration was published on the INPLASY website with the following registration number: INPLASY202240158 and the DOI number: 10.37766/inplasy2022.4.0158.

In the present study, "new devices" means that new and/or innovative data sources are now possible to obtain in volleyball due to the development and use of the respective devices. We examined studies using observational designs: cohort, case, and control and cross-sectional.

The STROBE checklist (78) was used to mitigate any biases, and it was applied by two authors (RLSG and CRC).

Search Strategy

The following electronic databases (PubMed, Scielo, VHL, Scopus, SPORTDiscus, Cochrane Library, EMBASE and Web of Science) were systematically searched until April 2024. The command line ("volleyball") and ("acceleromet*" or "gyroscope" or "inertial" or "sensor" or "wearable" or "measurement unit" or "wearable system" or "device" or "IMU" or "MEMS" or "microelectromechanical" or "VERT") and ("jump" or "activity profiles" or "specific movements") was used during the electronic search.

Eligibility Criteria

Titles and abstracts were reviewed based on the following **inclusion criteria** by 2 authors (VCSJ and MCIO): (a) the study was published as original research in a peer-reviewed journal as a full-text article; and (b) the data were reported from the use of some monitoring device and/or quantification of jumps and specific volleyball actions (the device must be developed and/or validated for the sport of volleyball). After this first screening, the **eligibility criteria** according to PECO were applied to the remaining complete manuscripts. (***P***) *participants:* healthy, volleyball athletes of any age, sex, and level. (***E***) *exposure:* exposure to assessment, training, and/or competition. (***C***) *comparators:* control groups are acceptable, but not mandatory. (***O***) *results:* data reported from the device.

Data Extraction and Synthesis

A data extraction form was developed to collect key information from the selected studies (VCSJ and CETC). The results were synthesized concerning the places of origin of technological innovations (e.g., device, company, and country), and the research carried out with the devices (e.g., institutions, authors, and country) worldwide. Furthermore, the extracted parameters included measures that refer to the data veracity (i.e., accuracy, quality, relevance, uncertainty, reliability, and predictive values of the collected data), experimental design (CACF), sample information, objective, and main findings. Some examples of data veracity extracted were coefficient of variation (CV), intraclass correlation coefficient (ICC), and limits of agreement (LOA), and standard error of measurement (SEM) among others.

RESULTS

Identification and Selection of Studies

The initial search identified 426 references. After removing the duplicates, 232 studies were screened for titles and abstracts that excluded 139 studies. Ninety-three full-text studies were selected and 54 of these were excluded, leaving 39 studies in the final analysis (Figure 1).

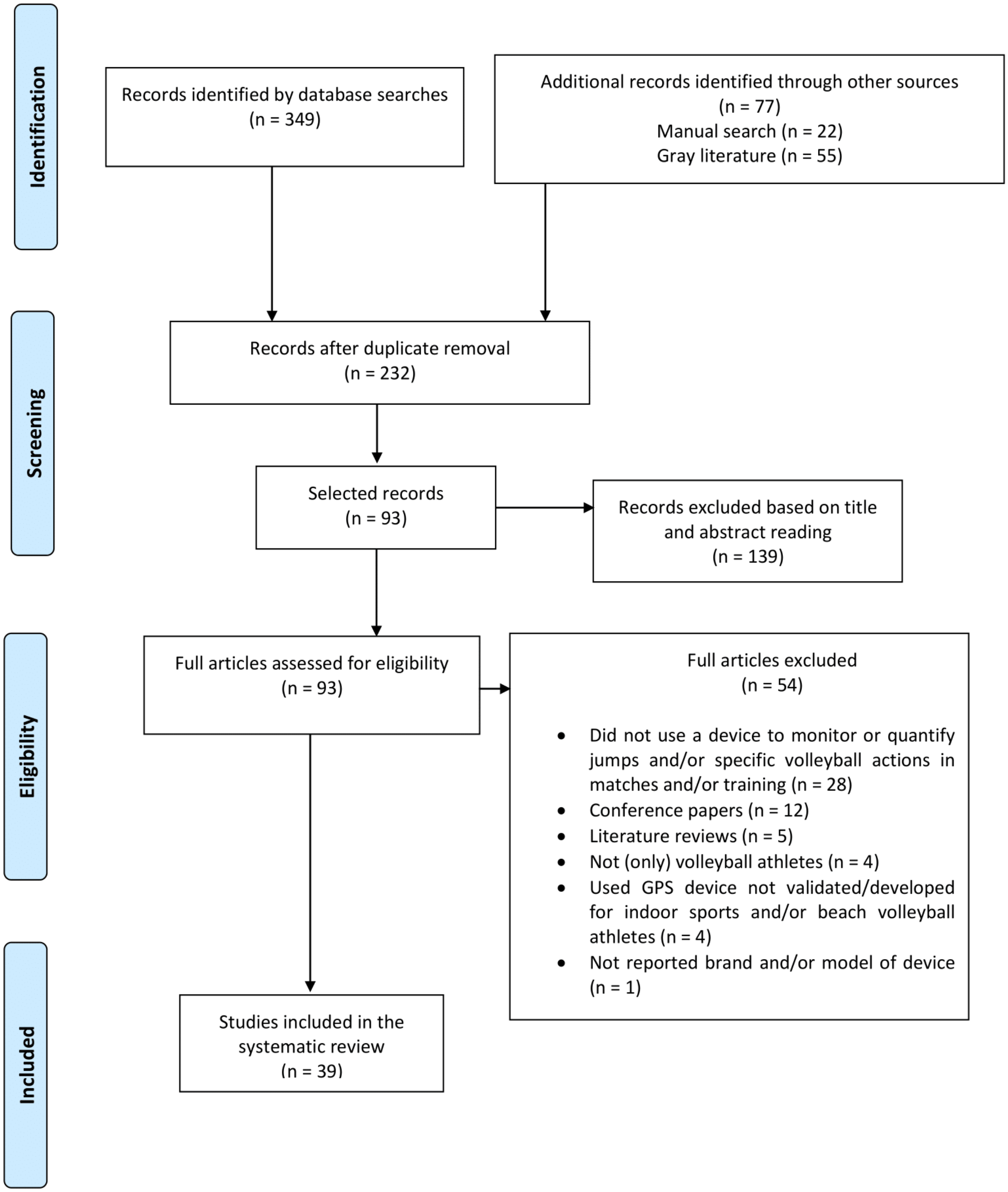

Figure 1. Flowchart of the Study Selection Process and the Reasons for Excluding Studies on Using Devices to Monitor or Quantify Jumps and/or Actions in Volleyball.

Description of the Studies

Table 1 provides a detailed analysis of the 39 studies included in this review. The total sample size of the selected studies was 697 participants (range = 6 to 112) with an age range of 22 ± 4 (range = 12 to 34), and an intervention duration of 87 ± 106 days (range = 1 to 300). The study samples were composed mainly of men (67%) while other samples were with women (28%), and some studies analyzed both sexes (5%).

Regarding the level of the participants, the most representative sample was professional athletes (58%), followed by university students (23%), elite youth (12%), high school students (3%), and recreational athletes (3%). Regarding the objectives of the studies, 64% focused on monitoring and quantifying external load (4,7,10,11,26,27,29,31,37,39,40,43,45,49,51,52, 57,59,60,70,74,76,83), 24% on determining the validity and reliability of the devices (9,15,25,35,41,44,53,54,56), and 13% on describing the differences between the playing positions (48,45,60,72).

A total of 72% of studies did not calculate the data veracity for the device(s) used in the respective studies (4,7,10,11,26,27,29,31,37,39,40,43,45,47-51,57,59,70,74,76,83). The studies were analyzed using the STROBE method (Supplementary Material 01).

Table 1. Characteristics of the Studies Included in the Review.

Year and first author	Sample	Sex/age (± years)	Team level	Number of days	Device (company, country)	Data analysis (lab, training, and/or match)	Aim	Main results	Veracity data	Study design
2007, Elvin	6	Male (27 ± 7)	Recreational	Not reported	Zero-Point (Zero-Point Technology, South Africa)	Lab (test session)	Determine load based on force and acceleration	High correlation between ground reaction force and axial tibial acceleration (r^2= 0.812, p< 0.01)	Not calculated	Correlation study / observational
2015, Jarning	12	Male (23 ± 2)	Professional	Not reported	ActiGraph GT3X (ActiGraph TM, USA)	Training	Determine if acceleration measured by an accelerometer identifies jumps	The serve and the attack could not be distinguished as movements without a jump (p= 0.422 to 0.999)	Not calculated	Cross-sectional study design
2017, Charlton	18	Male (17 ± 2)	Elite youth	Not reported	Vert device (My Vert, USA)	Training and matches (full season)	Determine the validity and reliability of IMU	High correlation between device IMUs (r= 0.83-0.97); differences between devices and motion analysis (3.57 and 4.28 cm); lack of precision in height measurement; counting accuracy 0.998 (0.995-1.000%)	Mean bias (underestimated): Vert 1= 3.57 cm and Vert 2= 4.28 cm, 10% for all jumps. The percentage of jump height underestimation ranged from 7% for block jumps to 48% for set jumps. Accuracy for all jump types = 0.974-1.00. Recall for block, spike and serve movements = 0.957-0.991 and set jump = 0.754	Concurrent validity design / Validation study
2017, Vlantes	11	Female (20 ± 1)	College	240	Optimeye S5 (Catapult, Austrália)	Match (full season)	Describe internal and external loads and relate them to each other	Differences between playing positions in internal and external load (p< 0.01); Difference between sets of matches (p< 0.05).	Not calculated	Prospective cohort / observational
2017, Borges	112	Male (18 ± 1)	Elite youth (U-18)	3	Vert device (My Vert, USA)	Lab (test session)	Determine the reliability of IMU	Differences in attacking jumps 70.9 ± 8.2 and 76.3 ± 7.5 cm (r = 0.75); Differences in blocking jumps 53.7 ± 6.1 and 58.5 ± 5.7 cm (r = 0.75); Overestimation of the IMU of attacking jumps (7.1%) and blocking jumps (8.2%)	VERT showed an acceptable CV for both attacking jumps (7.8%) and blocking jumps (7.9%); the scores measured with VERT overestimated the variable criterion by ~7.1% (AJ) and ~8.2% (BJ); blocking jumps' performance in this study was 23.3% lower than attacking jumps	Concurrent validity design / Validation study
2017, Macdonald	13	Male (Not reported)	Elite youth	Not reported	Vert device (My Vert, USA)	Training and matches	Determine the validity and reliability of the IMU	Overestimation of competition counts; High sensitivity in practice (96.8%); Underestimated height (2.5 to 4.1 cm)	The IMU systematically underestimated vertical displacement, with an average error of approximately 4.2% for maximal jumps and 5.5% for submaximal jumps. The random error was less pronounced, estimated at approximately 3.7% for maximal jumps and 3.4% for submaximal jumps	Concurrent validity design / Validation study

2018, Skazalski	14	Male (Not reported)	Professional	1	Vert device (My Vert, USA)	Training and matches (3 and 2, respectively)	Validity and reliability of this method to count jumps and measure jump height	The vert device demonstrates excellent accuracy in counting volleyball-specific jumps during both practice and match play. However, it overestimated jump height. In summary, it was indicated for quantification, but not for monitoring jumps in volleyball practice.	The Vert device accurately counted 99% of the 3637 jumps performed during practice and match play. The device showed excellent jump height inter-device reliability for two devices placed in the same pouch during volleyball jumps (r = 0.99, 0.98 to 0.99). The device had a MDC of 9.7 cm, an ICC = 0.85 (0.80 to 0.89) and overestimated jump height by an average of 5.5 cm (4.5 to 6.5) across all volleyball jumps.	Concurrent validity design / Validation study
2019, Lima	5	Male (27 ± 7)	Professional	12	Vert device (My Vert, USA)	Matches	Describe load, playing positions and microcycle	Lifters jump more than central midfielders and opposite midfielders; Differences within the microcycle	Not calculated	Prospective cohort / observational
2019, Lima	7	Male (27 ± 7)	Professional	90	Vert device (My Vert, USA)	Matches (5)	Descriptions of jumps in positions and game series	Useful for controlling and individualizing the external training load	Not calculated	Descriptive study / observational
2018, Montoye	20	Female (19 ± 1)	College	91-98	Blast Athletic Performance B0113 (Blast, USA)	Matches (5)	Determine the validity and reliability of the IMU	Moderately high correlation between Vertec and IMU data (r= 0.67 (SVJ) and r=	Blast significantly underestimated SVJ values by an average of -9.2 cm and OSJ values by	Concurrent validity design / Validation study

								0.69 (OSJ); Blast underestimated the height of the SVJ and OSJ (-9.2 cm and -10 cm)	an average of -10.0 cm; in 93.9% of SVJs and 96.8% of OSJs, Blast had lower jump height predictions than Vertec. The SVJ and OSJ trends measured by Blast did not follow the same trends as Vertec	
2019, Jaszczur-Nowicki	12	Male (20 ± 2)	College	180	WIVA system (LetSense Group, Italy)	Matches and training (6 months)	Compare jumps at the beginning and end of the season	There were no significant differences in the CMJ jumps; Significant differences in the CMJ+B jump (p=0.0414 and p=0.002)	Not calculated	Descriptive study / observational
2020, Lima	8	Male (23 ± 5)	Professional	105	Vert device (My Vert, USA)	Training (15 weeks)	(i) to characterize the external and internal training load of professional volleyball players with a focus on intra-week changes and (ii) to test the relationships between internal and external load measures.	Positive relationship between RPE and number of jumps (r= 0.17)	Not calculated	Prospective cohort / observational

2020, Soylu	22	Female (20 ± 4)	Professional	4	Vert device (My Vert, USA)	Lab (4 days of test sessions with 24 hours between each session)	Identify performance-related factors	Relationships between the H:Q ratios at both speeds were associated with vertical jump height (CMJ) and FMS scores (p<0.05)	Not calculated	Cross-sectional study/ Observational
2020, Radu-Cristian	12	Male Not reported	Not reported	Not reported	Vert device (My Vert, USA)	Lab (test session)	Compare IMU to traditional high jump measurement methods	There was a slight difference between the values of the Vert measurement and the values of the traditional methods	Not calculated	Concurrent validity design / Validation study
2021, Kupperman	11	Female (19 ± 1)	College	110	Clearsky T6 (Catapult, Austrália)	Training and matches (full season)	Quantify the external and internal load over a season and describe the differences between playing positions	High correlation between RPE and IMU data (p< 0.001); Significant differences in IMU data between playing positions (p<0.001/>0.004)	Not calculated	Retrospective cohort / observational
2021, Damji	14	Male (n= 11); Female (n = 3); (21 ± 2)	College	1	Vert device (My Vert, USA) e Shimmer3 IMU (Shimmer Sensing, Ireland)	Lab (test session)	Compare two IMUs between landing impact data and acceleration data	Low concordance correlation coefficient. Calculated at 0.37 (95% CI: 0.12 to 0.58)	The limits of agreement of -84.13% and 52.37% show that the percentage differences between VERT and Shimmer vary greatly. The calculated ICC is 0.49 (95% CI: 0.38 to 0.60)	Concurrent validity design / Validation study

2021, Markovic	13	Female (25 ± 3)	Professional	1	LSM6DS33 (ST Microelectronics, Switzerland)	Lab (test session)	Determine the validity and reliability of the IMU	High levels of validity for estimating jump height (CMJ t = 0.897, p= 379; ICC = 0.975; SQJ t = 0.564, p= 0.578; ICC = 0.921) and reliability (ICC > 0.872).	The difference in jump height (JH) between FP and IMU data was not statistically significant (p = 0.379); High ICC values were found (0.888 for CMJ and 0.872 for SQJ); Average coefficients of variation were 4.116% for CMJ and 5.933% for SQJ	Concurrent validity design / Validation study
2022, Altundag	14	Female (22 ± 1)	Professional	300	Kinexon LPS (Kinexon GmbH, Germany)	Training and matches (full season)	Monitoring the training load, recovery and performance of players	Positive and negative relationships between competition and training load data obtained from LPS data	Not calculated	Prospective cohort / observational
2022, García-de-Alcaraz	13	Female (28 ± 7)	Professional	2	WIMU PRO (RealTrack System, Spain)	Training (2)	Determine the reliability of IMU	High intraclass correlation coefficient of 0.99 for quantifying jumps	It showed a high level of agreement (ICC = 0.99). 12 jumps were not recorded on the device (false negatives). This corresponds to 0.76%; the percentage of agreement between the two instruments was over 99%	Concurrent validity design / Validation study
2022, Gielen	8	Male (20, 16 to 32)	Professional	300	Zephyr BioHarness 3.0 (Medtronic, USA)	Matches (full season)	Determine relationships between external and internal load	99% of the jumps were identified; flight times were underestimated	Not calculated	Descriptive study / observational

								(0.015 s ± 0.058 s)		
2022, Cabarkapa	18	Male (21 ± 3)	Professional	Not reported	Vert device (My Vert, USA)	Training (3 consecutive training sessions)	Compare external load between positions	Significantly different when compared to lifters and opposites (p< 0.05)	Not calculated	Cross-sectional study design
2022, Taylor	16	Female (20 ± 1)	College	120	Vert device (My Vert, USA)	Matches and training sessions (full season)	Examine jump loading demands in training and competition and describe injury patterns	Subjects who participated in more than 90% of the sets had higher JC (p= 0.003; d= 0.48) and JL (p= 0.003; d= 0.59) during the matches	Not calculated	Prospective cohort / observational
2021, Setuain	12	Male (24 ± 5)	Professional	1	MTx (XSens Techonolgies BV, The Netherlands) and Vert device (My Vert, USA)	Lab and training	Analyze performance and mechanics after training load	Reduction of 10% (p= 0.02) in vertical ground reaction force (VF2); ES values of 0.2, 0.5 and >0.8 represented small, moderate and large differences	Not calculated	Pre-post study design / experimental
2022, Esen	23	Female (15 ± 2)	School	2	Vert device (My Vert, USA)	Lab (2 test sessions)	Identification of the performance impact of the use of dynamic tape	There was no significant difference in vertical jump height in any of the parameters (p> 0.05)	Not calculated	Crossover randomized controlled trial study / experimental
2022, de Leeuw	25	Male (27 ± 3)	Professional	168	Vert device (My Vert, USA)	Matches and training sessions (complete Cup)	Identify the performance of volleyball players in different types of actions during matches	Performance was worse if the change in the number of high heels (>65 cm) in the previous week was greater than	Not calculated	Prospective cohort / observational

								9.75 heels or if the average number of high heels in the previous two weeks was greater than 11.6.		
2022, Piatti	12	Male (26 ± 2)	Professional	300	Vert device (My Vert, USA)	Matches and training	Measure and compare jump load and dynamic performance (best jump height, mean jump height, number of jumps for game/practice and proportion of jumps higher than 50cm) during entire season, and determine if jump load and performance was influenced by player position	Among the players position, middle blockers present the greatest jump load during the season. The setter presented the smallest jump loads during season.	CVs (*i.e.*, SD/average*100) between 6.6% and 44.4% depending on players' position and jump style.	Prospective cohort / observational
2022, Pawlik	14	Male (16 to 18)	College	5	Vector S7 (Catapult, Australia)	Training (5 sessions)	Determine the relationship between external and internal load	Accelerations showed a significant relationship with the number of jumps (p= 0.009); the number of jumps correlated significantly with low (p= 0.02) and medium (p= 0.027)	Not calculated	Descriptive study / observational

								accelerations, and also with the number of decelerations (p= 0.020)		
2022, de Leeuw	10	Male (27 ± 3)	Professional	168	Vert device (My Vert, USA)	Matches and training	Identify and correlate injury risk through external stress and wellness indicators over the course of a season	70% of players who reported "difficulty in training" were related to jumping loads; large differences between players	Not calculated	Prospective cohort / observational
2022, Lima	14	Male (22 ± 4)	Professional	240	Vert device (My Vert, USA)	Matches and training (full season)	Evaluation of the internal and external load intensity	Both RPE and s-RPE methods are useful for adjusting and monitoring training programs	Not calculated	Descriptive study / observational
2023, Jimenez-Olimedo	13	Female (22 ± 3)	Professional	7	IMU VmaxPro (Blaumann and Meyer-Sports Technology UG, Germany)	Lab (2 test sessions separated by 7 days)	Determine the validity and reliability of the IMU	There is a strong correlation between Vmaxpro and MoCAP (rs= 0.844), a weak agreement (CCC = 0.219)	Significant differences between Vmaxpro and MoCAP in measured jump heights (p< 0.001); Vmaxpro showed an average difference of -10.58 cm compared to MoCAP; a strong Spearman correlation (rs= 0.847, p< 0.001) and a weak concordant agreement (CCC= 0.219) were found between Vmaxpro and MoCAP measurements	Concurrent validity design / Validation study

2023, Keskinoglu	14	Male (12 ± 1)	Elite youth	Not reported	M5Stick (M5Stack, China)	Lab (350-jump test session)	Determine the reliability of the IMU	Correlation coefficient (r^2) between the two systems: 0.92	A high correlation (r^2 = 0.92, n = 350) was found between the VJH measurements; Bland-Altman analysis showed a bias of 20.06 cm between the two systems	Concurrent validity design / Validation study
2023, Lima	7	Male (31 ± 4)	Professional	21	Vert device (My Vert, USA)	Training (15 sessions).	Identify the effects of training load and match play on performance	Positive, large and significant correlation between the number of jumps and jump height: r=0.573 (95% Confidence Interval: 0.553 to 0.593; p<0.001)	Not calculated	Pre-post study design / experimental
2023, Lima	12	Male (22 ± 4)	Professional	240	Vert device (My Vert, USA)	Training and matches (full season)	Evaluate internal and external load intensity	Perceived exertion (RPE) and total session exertion (Session-RPE) showed strong correlations with the number of jumps (0.68 and 0.82)	Not calculated	Prospective cohort / observational
2023, Cabarkapa	10	Male (21 ± 2)	Professional	30	Vert device (My Vert, USA)	Training (mid-season)	Identifying force-time metrics during countermovem ent vertical jumps (CVJ)	A strong positive association between RPE and Stress (r= 0.713) and RPE and Jumping (r= 0.671)	Not calculated	Pre-post study design / experimental
2024, Bouzigues	37	Male (n = 21; 15 ± 1) and Female (n = 16; 14 ± 1)	Elite youth	270	Vert device (My Vert, USA)	Training (full season)	Monitor training load and jump performance	Weekly Injury Index: Lower in men (p<0.001)	Not calculated	Prospective cohort / observational

2023, Muñoz	12	Female (17 ± 1)	College	90	Vert device (My Vert, USA)	Matches and training (5 months)	Analyze the performance data	TJ (Total Jumps): p< .001, ES= 0.645 (large); p= .043, ES= 0.269 (moderate); HJ (High Jumps): p= .043, ES= 0.269 (moderate)	Not calculated	Descriptive study / observational
2022, Lima	10	Female (24 ± 6)	Professional	70	Vert device (My Vert, USA)	Training (32 sessions)	Monitor training loads	Moderate correlation between the measures	Not calculated	Prospective cohort / observational
2024, Kerpe	24	Male (23 ± 4)	Professional	35	Clearsky T6 (Catapult, Australia)	Training (15 sessions)	Monitor and compare the training load	There was no split effect for all external load measurements, except for tJUMPmin (p= 0.002)	Not calculated	Descriptive study / observational
2024, Bache-Mathiesen	65	Male (25 ± 6)	Professional and College	Not reported	Vert device (My Vert, USA)	Matches and training (3 seasons)	to investigate heel load and its association with knee complaints	Weekly jumping load of 35,000 arbitrary units, the probability of injury is 1.2%	Not calculated	Prospective cohort / observational

Figure 2 (Top) shows the 16 innovative devices produced in 10 different countries. Among the selected studies, the most commonly used device was Vert (63%), followed by Clearsky T6 (5%), Optimeye S5 (3%), M5Stick (3%), Kinexon LPS (3%), WIMU Pro (3%), IMU VmaxPro (3%), Zephyr BioHarness 3.0 (3%), MTx (3%), Vector S7 (3%), LSM6DS33 (3%), WIVA System (3%), ActiGraph GT3X (3%), Shimmer3 (3%), Blast B0113 (3%), and Zero-Point (3%).

Figure 2 (Bottom) shows the researchers of the studies selected for this review from 21 countries and 83 institutions. There were 9 studies by researchers in the United States (14%), 8 in Brazil (13%) and Portugal (13%), 6 in Spain (10%), 4 in Norway (6%) and Turkey (6%), 3 in Qatar (5%) and Canada (5%), 2 in Belgium (3%), Poland (3%), the Netherlands (3%), and Slovenia (3%), and 1 each in Iran (2%), France (2%), Australia (2%), Russia (2%), Lithuania (2%), Germany (2%), Serbia (2%), and South Africa (2%).

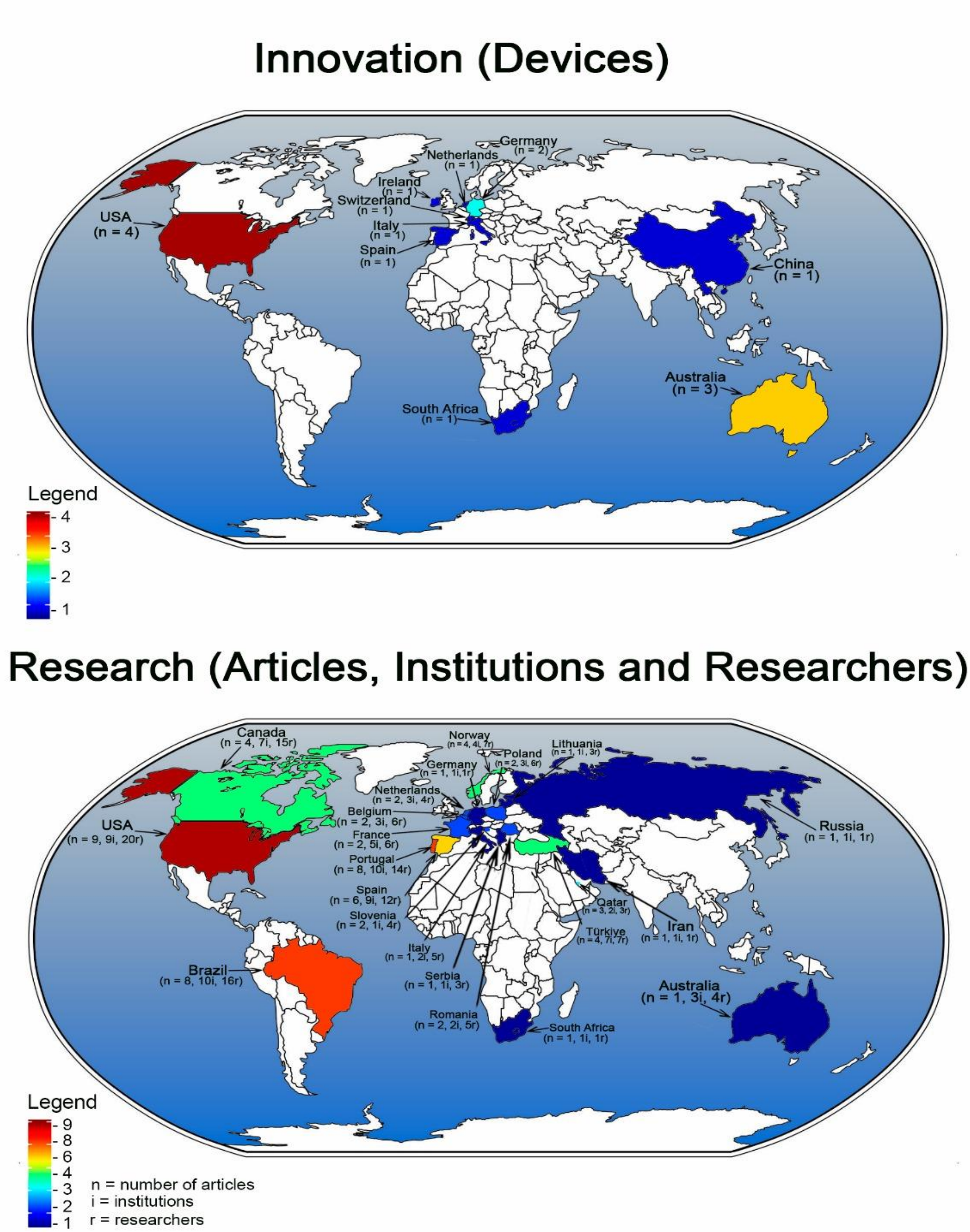

Figure 2. Devices for Monitoring and Quantifying Jumps and/or Specific Volleyball Actions: Global Production of Research and Innovation.

DISCUSSION

This study verified the devices available for monitoring and quantifying jumps or specific actions in volleyball as well as the veracity of their data in scientific literature through a systematic scoping review. Sixteen innovative devices were found in the 39 published articles. Few data veracity of devices (28%) was calculated in these studies and a common situation found was the use of intraclass correlation index (ICC) and/or Pearson's correlation coefficient (r) to determine the reliability/agreement of the measurements. In general, the studies conducted in volleyball using devices for monitoring and quantifying jumps or specific actions aim to determine the load applied in the athletes, in addition to validating and evaluating the reliability of the devices in counting and measuring vertical displacements.

The validity metrics for quantifying jumps were shown to be good to excellent, while the reliability measures for estimating height presented conflicting results. When used in real environments, these devices proved to be more suitable tools for quantification, but they still need improvement to monitor jumps and/or specific volleyball actions.

The main objectives of the selected studies were to determine the external load, followed by analyzing the validity and reliability of the devices and describing differences between playing positions. Studies on external load address the physical demands imposed on athletes during training and competitions as well as evaluating the correlation between external and internal load. This focus is important since it can contribute to reducing the risk of injuries and optimizing sports performance (27,59). Some studies analyzed the correlations between external load and performance; internal load and performance; external load and internal load. The correlations were often classified according to Cohen (22): 0.10 to 0.29 small; 0.30 to 0.49 medium; 0.50 to 1.00 large. Most studies reported high correlations between external load and performance (10,24,47,50,57), internal load and performance (37), external load and internal load (45,51,83), which highlighted the usefulness of the devices in monitoring and/or quantifying specific volleyball actions.

The tracking of performance during matches by quantifying the number of jumps between sets has been reported as a great utility that has recently enabled using devices (48). The use of devices for monitoring and quantifying has also allowed the identification of differences between playing positions in terms of the number of jumps and the height reached in the jumps (4,7,24-27,29,31,35,40,41,43-45,47,49-51,54,57,59,60,70,72,74,76,83).

The monitoring and quantification of jumps in volleyball seems to be an indicator of greater interest to coaches, as the data provided served to manage the training load and the performance of athletes on an individual basis (52,70). The analysis of jump quantity and quality during training and games is critical due to its relation to performance (8). However, the usage of these devices warrant caution, given that not all the devices were able to accurately identify the frequency of jumps in volleyball (39). In general, the results of studies investigating the reliability of measurements indicate that the devices tend to present errors when monitoring jump height, and in some cases overestimated the height (9,72), and in others underestimated (15,37,53,56) the results. The variations shown by the devices can be attributed to the different approaches and technologies of the devices used to measure vertical jump height (e.g., accelerometers, gyroscopes, and/or magnetometers), and it may be necessary to move beyond the black boxes to obtain better results. One good action is to increase the validation studies in ecological contexts and varied groups, particularly more in women and nonprofessional athletes, as well as incentivizing replication studies. There is limited research on device location, but a selected study in this scoping systematic review suggested that the devices should be placed near to the center of mass (72). Furthermore, a systematic review on the usage of accelerometers in invasion sports indicated that the most frequent devices' body location was at the scapula because of its optimal signal reception for time-motion analysis (36). Therefore, further analysis on device body location, and the effect on the reliability of "jump and action" data is warranted.

The transformative potential of technological innovations in the sporting context has been highlighted in scientific literature (21,23,64). However, regarding the statistical approaches used, we and other authors of systematic reviews in the same field (e.g., reference 81) recommend reflecting on their potentialities and limitations, including the interpretation of the individual results of the selected studies. For example, the non-recommended use of Pearson's correlation coefficient (r) to establish the agreement of measurement because it may only be reporting a correspondence in the direction (e.g., horizontal) and/or sense (i.e., the left or right) of variation of the outputs/measurements between the devices evaluated, and not necessarily a correspondence in repeatability between the outputs/measurements reported by each device (2,38,80,81). Furthermore, the use of parameters with recognized limitations for determining reliability (e.g., the ICC) (84) generate confusion in the findings, especially in the interpretation and the practical application. Regarding ICC, where low repeatability is concurrent with a high variance between subjects, the values can result in an ICC with a good/excellent classification (84). A joint analysis of the ICC with the standard error of measurement (SEM), relative and absolute, is recommended to minimize these confounding factors (18).

The results of this systematic scoping review show that devices for monitoring and quantifying jumps in a volleyball were produced in 10 different countries; whereas, the researchers of the selected studies were from 21 countries (i.e., a ratio of 2.1:1; studies: devices). An interesting fact about these countries is that there is a constant frequency of countries that produce innovation (devices) and/or research (articles, institutions, and researchers) (Figure 2) also in the FIVB women's and men's rankings (senior, U21, U19, U17). In general, the effect of research and development (R&D) activity on the level of innovation was reported for European countries, and a significant correlation between the development of R&D activities and innovation performance (61). In sports, despite similar analysis with a focus on sport performance has been suggested, i.e., investing in Research, Development & Innovation (RD&I) for and in Sport to achieve better results in sports performance (28,55,63,82). Few studies are still found in the scientific literature and one current study found promising results for RD&I in sports (30) that encourages more research.

Our sample was mostly composed of professional athletes and men, corroborating with systematic reviews of our group related to sport where the vast majority of sample were men (i.e., minimum = 70% male; maximum = 100%; mean = 90%; median = 94% and mode = 95% and 97%) (1,16-18,20,51,73). This fact indicates the need for more support and studies examining female athletes. The under-representation of women in sport has been discussed for a long time (5,13,14,33), but it remains. Clearly, we need more concrete actions to change this scenario.

New devices for monitoring and quantifying in volleyball showed great potential to contribute to both main objectives of load management, i.e., enhancing performance and reducing injury risk during matches and/or training sessions. Future research should focus on developing sensors that can guarantee higher reliability of the devices and perform data analytics in real time with instantaneous feedback to the Coaching Staff. An intriguing point arising from the analysis of this systematic scoping review is that 72% of the studies did not calculate the data veracity for the device(s) used in the respective studies. In another study with team sport, data veracity was not found for 46% of tools analyzed (18).

Our findings indicate a need to improve the availability of data veracity of devices to better inform and prepare volleyball training professionals based on clearer information. Because the lack of data veracity reported in the devices used does not contribute to improving the understanding of the practitioners and researchers as well as to maximizing the benefits of these technological innovations in sports. Therefore, age group analysis, specifically females, should be noted. The measurement devices in pre-adolescents, particularly in regards to their physical development is also warranted.

CONCLUSIONS

Volleyball is truly a cutting-edge sport and, from the 1950s to the present day, based on what we were able to verify in the scientific literature, it has been applying and taking advantage of the technological innovations available in the field to grow the sport. The most recent advances allow for monitoring and quantifying jumps and/or specific actions in volleyball. However, there remains a need to develop these devices to perform the deliveries with an adequate level of data veracity. A good way to accelerate the development in volleyball is by the integrated work between the university (i.e., the institutions and/or the researchers) and the industry, which includes the teams, the coaches, the athletes, the companies, and the startups. Without question, this where much of the current bottlenecks and "black box" information could be solved. This systematic scoping review does not intend to conclude this discussion, but rather to begin this reflection with some directions that the current state of the art allows us to point out for the advancement of the area.

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