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An Investigation of Physical Fitness in Spartan Race Participants

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ABSTRACT

Mami Yoshimura, Miki Takimoto, Toshihisa Kojima, Toru Terashima. An investigation of physical fitness in Spartan race participants. The purpose of this study was to investigate the physical fitness of recreational male participants in a Spartan Race. Nine men who competed in the Beast category of the Spartan Race in Niigata participated in this study. Measurements included body composition, muscle strength at 5 sites on both sides of the body, maximal and 30-second anaerobic power of the arms and legs, 2 types of jump height, a 20-meter shuttle run test, and a 5-minute burpee test. After the race, the number of obstacles successfully completed by each participant was recorded. The participants' mean height, body weight, and body fat percentage were 172.9 ± 4.8 cm, 63.9 ± 7.1 kg, and 14.3 ± 4.1%, respectively. Knee extension strength of the right leg at 60°/sec was 3.0 ± 0.5 Nm/kg. Maximal anaerobic power of the arms and legs was 6.7 ± 0.9 W/kg and 13.9 ± 2.8 W/kg, respectively. Thirty-second anaerobic power of the arms and legs was 5.0 W/kg and 8.6 ± 0.9 W/kg, respectively. Jump height was 46.2 ± 7.1 cm, 5-minute burpee count was 71 ± 9, and 20-meter shuttle run count was 109 ± 13. Because the success rate on hanging-type obstacles was low, strengthening through body weight-based training may be considered to improve performance.

Key Words: Maximum Anaerobic Power, Muscle Strength, Obstacles, Spartan Race

INTRODUCTION

Obstacle course racing (OCR) is a popular sport worldwide. It involves running while overcoming natural terrain and artificial obstacles, making it distinct from conventional running. Obstacles may include climbing walls or ropes, carrying heavy objects, and, in some races, moving through mud and water. Race distances also vary, ranging from several kilometers to several tens of kilometers. Therefore, in addition to the endurance required for running, strength and specific skill proficiencies are also necessary (7,10). Representative OCRs include the Spartan Race (16), Tough Mudder, and the OCR World Championships. Additionally, although not officially recognized by World Athletics (WA), the Fédération Internationale de Sports d'Obstacle (FISO) organizes various obstacle competitions, including OCR events (8).

The Spartan Race is one of the largest OCRs in the world, with events held in 40 countries and 170 races annually (16). It was originally established in the United States in 2009, and the first race in Japan was held in 2017. In Japan, 5 races are held annually, but in 2025, 6 races will be held for the first time.

Spartan Races are categorized based on their distance and the number of obstacles participants must traverse. The 4 main Spartan Race levels include Sprint, Super, Beast, and Kids Race. The Sprint is a 5 km race with 20 obstacles, the Super is a 10 km race with 25 obstacles, and the Beast is a 21 km race with 30 obstacles. Additionally, there are Elite, Age-based, and Open categories, some of which offer prize money. In the Open category, participants can assist one another in overcoming obstacles. However, if participants fail to complete an obstacle, they must perform burpees as a penalty, which is a distinctive feature of the Open category. The various levels and categories make the Spartan Race accessible to a wide range of participants, from beginners to advanced runners, regardless of age or gender.

In Japan, the Beast is held annually only at Niigata in September, attracting vast numbers of participants each year. Obstacles include the 6-foot wall (approximately 2 m high), the Monkey Bar, where participants must ring a bell at the end, the Barbed Wire Crawl, in which participants crawl under barbed wire, and the Slip Wall, where participants climb a slanted wall using a rope. The Beast race is held at a summer ski resort, and participants must ascend to an elevation of 800 m by the first obstacle, located approximately 2.5 km from the start. The course uses the ski resort's terrain, so the participants must not only clear obstacles but also run uphill and downhill, resembling a trail run. Therefore, both full-body strength and endurance are required to complete the race successfully.

Bishop et al. (4) evaluated physical fitness related to OCR performance in 47 male participants. They reported that, compared with slower participants, the participants who completed an indoor obstacle course test faster tended to have lower body weight and body fat percentage, as well as higher arm peak and mean anaerobic power per kilogram of body weight, leg aerobic power, leg press one-repetition maximum (1RM), and lateral pulldown 1RM.

Although several studies have examined physical fitness in OCRs among various athletes (2,6,9,19), to the best of our knowledge, no studies have specifically investigated the physical fitness of Spartan Race participants. Therefore, the purpose of the present study was to investigate the physical fitness of healthy males who participated in the Beast category of the Spartan Race.

METHODS

Subjects

Nine males (height: 172.9 ± 4.8 cm, weight: 63.9 ± 7.1 kg, age: 21.4 ± 2.3 years) participated in the study. All participants competed in the Beast category of the 2024 Spartan Race in Niigata. The purpose and methods of the study, as well as the potential risks associated with the measurements, were fully explained to all the participants both verbally and in writing, and a written informed consent was obtained from all the participants prior to their participation. In the case of underage participants, written consent was obtained from both the participant and their legal guardian prior to their participation in the study. This study was approved by the Ethics Committee of Toyota Technological Institute (Approval No. Toyota Technological Institute -Ethics-24-03).

Procedures

Body Composition

Height was measured using a stadiometer. Body weight, body fat percentage, muscle mass, and body mass index (BMI) were measured using a multi-frequency body composition analyzer (MC-780A-N, TANITA, Japan).

Muscle Strength

The participants were seated on an isokinetic dynamometer (BIODEX SYSTEM 3, BIODEX, USA), and measurements were conducted at two angular velocities, 60°/sec and 180°/sec. Maximal effort tests were performed for bilateral shoulder extension and flexion, elbow extension and flexion, hip extension and flexion, knee extension and flexion, and ankle plantarflexion and dorsiflexion, with 3 sets of 2 repetitions for each movement. Rest periods were provided between sets, and the peak torque per kilogram of body weight (Nm/kg) was recorded. Rest period durations were at the discretion of the individual.

Anaerobic Power of the Arms and Legs

For measuring the maximal anaerobic power of the arms, an electromagnetic-braked cycle ergometer (POWER MAX V3, KONAMI SPORTS CLUB, Japan) was used. The ergometer was fixed on a platform, and the pedals were replaced with an arm-cranking attachment. After sufficient rest intervals, 3 all-out arm-cranking tests of 5 to 10 seconds each were performed at 3 different loads: 0.0205 kp/kg, 0.041 kp/kg, and 0.0615 kp/kg (Figure 1a). Rest period durations were at the discretion of the individual. The relationship between the applied load and the maximal pedal revolution rate for each trial was examined with linear regression, and the maximal anaerobic power of the arms was calculated (18). Maximal anaerobic power relative to body weight (hereafter abbreviated as A-MAnP/BW) was also calculated.

For measuring the maximal anaerobic power of the legs, an electromagnetic-braked cycle ergometer (POWER MAX V3, KONAMI SPORTS CLUB, Japan) was used to perform all-out pedaling tests at 3 different loads: 0.05 kp/kg, 0.075 kp/kg, and 0.10 kp/kg (Figure 1b). Each trial consisted of 5 to 10 seconds of maximal pedaling at the specified load, with approximately 2 minutes of rest between trials. The relationship between the applied load and the maximal pedal revolution rate for each trial was examined with linear regression, and the maximal anaerobic power of the legs was calculated (18). Maximal anaerobic power of the legs relative to body weight (hereafter abbreviated as L-MAnP/BW) was also calculated. The correlation coefficient (r) between the applied load and maximal pedal revolution rate was 0.98 or higher in all measurements.

(a) (b)

Figure 1. Anaerobic Power Tests in the Arms (a) and Legs (b). Each test was performed using a Powermax under 3 different loads.

Thirty-Second Power Test

For measuring 30-second power, the same cycle ergometer used for the maximal anaerobic power test was employed. The participants performed 30 seconds of all-out arm cranking or leg pedaling, and the mean power output during this period was recorded. Values relative to body weight for the mean 30-second power of the arms (A-P30/BW) and legs (L-P30/BW) were also calculated. The loads for the arm-cranking and leg-pedaling tests were set at 0.0615 kp/kg and 0.075 kp/kg, respectively.

Jump Height

Countermovement jump (CMJ) height without arm swing and countermovement jump with arm swing (CMJA) height were measured using a jump mat (Multi Jump Tester II, DKH, Japan). For measuring CMJ, the participants placed their hands on their hips to eliminate arm swing (20,21). Each jump was performed 3 times, and the highest value was recorded.

Shuttle Run Test

The shuttle run was conducted in accordance with the rules of the New Physical Fitness Test issued by the Ministry of Education, Culture, Sports, Science and Technology of Japan. At the sound of an electronic signal, the participants ran to a line 20 meters away. Upon either foot crossing or touching the line, they turned around and waited for the electronic signal sound before running back to the starting line. This procedure was repeated until the participant failed to touch the line with either foot before the next electronic signal twice consecutively. The total number of completed shuttles up to the last successful turn was recorded.

Burpees

Burpees were performed according to the official method specified by the Spartan Race. First, the participants stood with their feet shoulder-width apart. Then, they lowered their hips and bent their knees to assume a squat position. Both hands were placed on the ground, both legs were extended backward into a push-up position, and the chest touched the ground. Then, they quickly jumped both feet forward toward their hands and returned to the squat position, fully extending their hips as they rose. After returning to the squat position, they performed a jump, ensuring that both feet left the ground completely. During the jump, they raised both hands above the level of their ears. Following these official Spartan Race rules (15), the number of burpees completed in 5 minutes was recorded.

Heart Rate

Heart rate was measured during the race using an optical heart rate sensor (Verity Sense, POLAR, Finland). Measurements were initiated by pressing the start button at the beginning of the race, and the participants pressed the stop button themselves upon finishing. The optical heart rate sensor was secured on the arm using the provided strap that was adjusted to avoid any discomfort.

Successful Obstacles

There were 30 obstacles in the Beast category (Table 1). After the race, each participant was asked to report the number of obstacles they successfully completed, and the responses were recorded and summarized.

Table 1. Obstacles.

Obstacle name		Overview
1	4ft wall	Climb over a 4-foot wall
2	6ft wall	Climb over a 6-foot wall
3	Paracord	Belly crawl up a slope beneath barbed wire
4	Plate drag	Pull a sled with weights
5	Vertical cargo	Scale the cargo net to reach the top
6	Monkey bar	Cross the monkey bars
7	Inverted wall	Climb a wall that leans toward the participant
8	Atlas carry	Lift and carry a heavy ball
9	Hurdles	Jump over the hurdle
10	OUT	Climb over walls and crawl through gaps
11	A frame cargo	Climb over an A-frame net
12	Rope Climb	Climb the rope
13	Z wall	Move forward while climbing over a wall that bends in the shape of the letter ‘Z’
14	Hercules hoist	Use a rope attached to a pulley to lift a weight
15	Multi rig	Move while hanging on rings
16	Sand bag carry	Carry a punching bag
17	Spear throw	Throw a javelin
18	Bucket carry	Carry a heavy bucket

19	**Barbed wire crawl**	**Crawling under barbed wire**
20	**Olympus**	**Move along a slanted wall using hand and foot holds**
21	**Bender**	**Climb over a slanted obstacle**
22	**Tyrolean traverse**	**Use a rope stretched between two points to suspend your body and move to the opposite side**
23	**Twister**	**Traverse rotating monkey bars**
24	**Armer**	**Lift and carry a heavy ball**
25	**7ft wall**	**Climb over a 7-foot wall**
26	**8ft wall**	**Climb over an 8-foot wall**
27	**Jerry can carry**	**Carry a jerry can**
28	**Stairway to sparta**	**Climb over a near-vertical wall and a ladder mounted at the top to reach the other side**
29	**Slip wall**	**Climb up a slope using a rope**
30	**Fire jump**	**Jump over a fire**

RESULTS

The age and physical characteristics of the participants are shown in Table 2. Muscular force at 60°/sec and 180°/sec is presented in Table 3. A-MAnP/BW and A-P30/BW, as well as L-MAnP/BW and L-P30/BW, are shown in Table 4. Jump heights are presented in Table 5. Results of the shuttle run test and burpee test are shown in Table 6. The number of obstacles successfully completed in the 2024 Spartan Race in Niigata is presented in Table 7. Heart rate could be recorded during the race for only four out of the nine participants. The missing data are attributable to participants failing to start the measurement properly when required to press the start button themselves, and displacement of the sensor when crossing obstacles or carrying objects. The maximal heart rates during the race for the four participants whose data were successfully recorded were 193, 184, 185, and 189 bpm.

Table 2. Participants' Age and Physical Characteristics.

N = 9	Units	Mean	±	SD
Age	(years)	22.9	±	3.2
Height	(cm)	172.9	±	4.8
Body weight	(kg)	63.9	±	7.1
BMI	(kg/m^2)	21.4	±	2.3
Body fat percentage	(%)	14.3	±	4.1
Muscle mass	(kg)	51.9	±	5.3

BMI: Body mass index. Data are presented as mean ± SD.

Table 3. Muscular Force at 60°/sec and 180°/sec.

60°/sec		Units	Right			Left		
			Mean	±	SD	Mean	±	SD
Shoulder	Extension	(Nm/kg)	1.1	±	0.1	1.2	±	0.1
	Flexion	(Nm/kg)	1.0	±	0.1	1.1	±	0.2
Elbow	Extension	(Nm/kg)	0.8	±	0.2	0.7	±	0.1
	Flexion	(Nm/kg)	0.7	±	0.1	0.7	±	0.1
Hip	Extension	(Nm/kg)	2.5	±	0.5	2.2	±	0.7
	Flexion	(Nm/kg)	1.8	±	0.3	1.7	±	0.4
Knee	Extension	(Nm/kg)	3.0	±	0.5	3.0	±	0.4
	Flexion	(Nm/kg)	1.6	±	0.2	1.6	±	0.2
Ankle	Plantar Flexion	(Nm/kg)	1.3	±	0.3	1.4	±	0.3
	Dorsiflexion	(Nm/kg)	0.4	±	0.0	0.4	±	0.1
180°/sec		Units	Right			Left		
			Mean	±	SD	Mean	±	SD
Shoulder	Extension	(Nm/kg)	1.1	±	0.1	1.1	±	0.1
	Flexion	(Nm/kg)	0.8	±	0.1	0.9	±	0.1
Elbow	Extension	(Nm/kg)	0.7	±	0.1	0.6	±	0.1
	Flexion	(Nm/kg)	0.5	±	0.1	0.5	±	0.0
Hip	Extension	(Nm/kg)	1.9	±	0.5	1.7	±	0.6
	Flexion	(Nm/kg)	1.4	±	0.3	1.3	±	0.3
Knee	Extension	(Nm/kg)	2.3	±	0.4	2.1	±	0.3
	Flexion	(Nm/kg)	1.3	±	0.2	1.3	±	0.2
Ankle	Plantar Flexion	(Nm/kg)	0.7	±	0.1	0.8	±	0.2
	Dorsiflexion	(Nm/kg)	0.3	±	0.0	0.3	±	0.1

Data are presented as mean ± SD.

Table 4. Anaerobic Power in the Arms and Legs and 30-Second Power.

N = 9	Units	Mean	±	SD
A-MAnP/BW	(w/kg)	6.7	±	0.9
L-MAnP/BW	(w/kg)	13.9	±	2.8
A-P30/BW	(w/kg)	5.0	±	0.5
L-P30/BW	(w/kg)	8.6	±	0.9

Data are presented as mean ± SD. **A-MAnP/BW:** Arm Maximal Anaerobic Power; **L-MAnP/BW:** Leg Maximal Anaerobic Power; **A-P30/BW:** 30-second average arm power per kilogram of body weight; **L-P30/BW:** 30-second average leg power per kilogram of body weight.

Table 5. Jump Hight.

n=9	Units	Mean	±	SD
CMJA Height	(cm)	46.2	±	7.1
CMJ Height	(cm)	39.7	±	7.0

Data are presented as mean ± SD. **CMJA:** Countermovement jump height with arm swing; **CMJ:** Countermovement jump height.

Table 6. Shuttle Run and Burpee Tests.

N = 9	Units	Mean	±	SD
Shuttles Completed	(counts)	108.6	±	13.0
Burpees Completed	(counts)	71.0	±	9.0

Data are presented as mean ± SD.

Table 7. Successfully Completed Obstacles.

Obstacle		Success rate (%)
1	4ft Wall	100
2	6ft Wall	100
3	Paracord	100
4	Plate Drag	100
5	Vertical Cargo	100
6	Monkey Bar	44
7	Inverted Wall	100
8	Atlas Carry	78
9	Hurdles	100
10	OUT	100
11	A Frame Cargo	100

12	**Rope Climb**	**100**
13	**Z Wall**	**78**
14	**Hercules Hoist**	**78**
15	**Multi Rig**	**67**
16	**Sand Bag Carry**	**89**
17	**Spear Throw**	**11**
18	**Bucket Carry**	**100**
19	**Barbed Wire Crawl**	**100**
20	**Olympus**	**33**
21	**Bender**	**56**
22	**Tyrolean Traverse**	**78**
23	**Twister**	**0**
24	**Armer**	**100**
25	**7ft Wall**	**100**
26	**8ft Wall**	**44**
27	**Jerry Can Carry**	**100**
28	**Stairway to Sparta**	**100**
29	**Slip Wall**	**100**
30	**Fire Jump**	**100**

DISCUSSION

In this study, the physical fitness of 9 healthy males who participated in the Beast category of the 2024 Spartan Race in Niigata was measured.

Titus et al. (17) examined OCR performance in 13 healthy males and 19 healthy females. In their study, the males had a height of 1.76 ± 0.08 m, a body weight of 76.35 ± 6.94 kg, and a BMI of 24.83 ± 2.85 kg/m². Race time was 44.53 ± 10.59 minutes, maximal oxygen uptake (VO_2 max) was 45.09 ± 6.87 ml/kg/min, Wingate mean power per kilogram of body weight was 7.17 ± 1.19 W, vertical jump height was 15.99 ± 3.64 inches, and the number of burpees completed in 5 minutes was 68.63 ± 14.59. Overall, their results suggest that both aerobic and anaerobic capacities contribute to OCR success.

In comparison, participants in the present study completed fewer burpees in 5 minutes and had lower vertical jump heights. In contrast, 30-second leg power was higher in the present participants. The participants in this study had lower burpee and vertical jump counts after 5 minutes, but they had higher 30-second leg power. Podstawski et al. (11) examined results of the 3-minute burpee test in 5,971 males and 3,862 females aged 18 to 25 years. Males completed 56.69 ± 9.52 burpees, and females completed 48.84 ± 11.43 burpees. The height, body weight, and BMI of the males were 180.99 ± 6.08 cm, 77.20 ± 9.77 kg, and 23.56 ± 2.71

kg/m², respectively. Despite the longer burpee test duration in the present study, the present participants completed fewer burpees.

Tsiokanos et al. (18) measured CMJ height (without arm swing), hip and knee flexor and extensor strength, and ankle plantar flexor and dorsiflexor strength in 29 male physical education students. Their CMJ height was 35.5 ± 4.1 cm. Hip and knee extensor strength and ankle plantar flexor strength at 60°/sec were 3.46 ± 0.58 Nm/kg, 2.86 ± 0.29 Nm/kg, and 1.13 ± 0.25 Nm/kg, respectively, while at 180°/sec they were 3.03 ± 0.61 Nm/kg, 1.89 ± 0.23 Nm/kg, and 0.64 ± 0.18 Nm/kg, respectively. In contrast, CMJ height without arm swing, knee extensor strength at 60°/sec and 180°/sec, and ankle plantar flexor strength were higher in the participants of the present study.

Skriver et al. (14) examined forearm grip strength, muscular endurance, and finger strength in 960 climbers and 301 non-climbers. Climbers had significantly greater grip strength and forearm endurance compared with non-climbers. Furthermore, when comparing lead climbers and boulder climbers, boulder climbers exhibited significantly greater finger strength. Grip strength and forearm muscular endurance were not assessed in the present study. Since the Spartan Race includes body weight-based obstacles, future studies measuring grip strength and forearm muscular endurance are warranted. In addition, except for the javelin throw, the participants' success rate for body weight-based obstacles, such as the monkey bars, was below 70%. Therefore, improving performance in body weight-based events may be important for successfully completing more obstacles.

Alvero-Cruz et al. (1) investigated the effects of body composition, VO_2 max, percent VO_2 max at the ventilatory threshold, work economy, and lactate levels on trail running performance in 11 male trail runners. The participants had a height of 173.21 ± 7.61 cm, a body weight of 68.09 ± 6.35 kg, a BMI of 22.67 ± 1.62 kg/m², a body fat percentage of 9.96 ± 1.35%, and a skeletal muscle mass of 31.48 ± 2.36 kg. In comparison, the participants in the present study had higher body fat percentage and skeletal muscle mass. Other studies on OCRs have also measured VO_2 max. Therefore, future studies should measure VO_2 max in Spartan Race participants, not only to assess its influence on the ability to clear obstacles but also to run on steeply inclined trails (12,13).

Bishop et al. (3) studied the effect of body weight on the performance of weight-supported exercise ability tests in healthy men and suggested that body weight only slightly affected the scores of the indoor obstacle course test. The participants in this study had a particularly low success rate on obstacles that involved moving while hanging, such as climbing ladders. As such, strengthening through bodyweight-based exercises may be an important factor in achieving success on more obstacles. Therefore, it is important that physical fitness factors related to bodyweight-based obstacles should be examined in the future.

CONCLUSIONS

The purpose of this study was to investigate the physical fitness of healthy males who participated in the Beast category of the Spartan Race. Compared with previous studies, the participants in the present study had lower results in the 5-minute burpee test and vertical jump height, while CMJ height (without arm swing), knee extensor strength at 60°/sec and 180°/sec, and ankle plantar flexor strength were higher.

Future studies should also measure balance, agility, and race duration to examine which skills and abilities contribute to successfully completing more obstacles and finishing the race faster. Heart rate was also measured in the present study; however, it could not be recorded in 5 out of the 9 participants. Creagh et al. (5) measured heart rate using a chest strap, but because some Spartan Race events involve carrying heavy objects, an arm-worn heart rate monitor with a strap was used in this study. Nevertheless, the displacement of the sensor when crossing obstacles or carrying objects may have caused inaccurate recordings. Future studies should employ measurement methods that can accurately capture heart rate during all types of movements.

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Progressive Load: The Forgotten Principle Behind Muscle Hypertrophy for Natural Bodybuilders

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ABSTRACT

Horn J. Strength training to build muscle has evolved over the past century with lifters employing various methods from advanced strength training techniques to specific nutrition methods to anabolic steroids. The principle of progressive overload is to gradually increase the exercise stress on the musculoskeletal system and the nervous system, which has been an accepted model to elicit strength training adaptations. However, the increase in load by itself as a facilitator to increasing muscularity is a debated strategy in recent years. Moreover, with the widespread adoption of anabolic steroids since the 1960s, progressive loading as a standalone variable may not be as relevant to enhanced individuals, but instead holds greater significance for those who do not use bodybuilding drugs. This critical review explores the significance of progressive mechanical tension and its role in hypertrophy. A structured literature search was performed in PubMed and Scopus using Boolean operators with terms such as natural bodybuilding, muscle growth in bodybuilding, and progressive overload resistance training. After screening titles and abstracts and applying inclusion and exclusion criteria, relevant sources were reviewed. Reference mining was also used to broaden the final analysis suggest that natural lifters benefit most from structured training that emphasizes progressive loading, while anabolic steroid users may not require the same form of progression and instead rely on volume as their primary driver for muscle hypertrophy. Hence, this review challenges the prevailing volume-centric paradigm in hypertrophy research for drug free lifters by concluding that progressive load and intensity of effort are the most critical drivers of muscle growth.

Key Words: Natural Bodybuilding, Muscle Hypertrophy, Progressive Overload

INTRODUCTION

Since the early 20th century, bodybuilders have consistently explored various methods to influence muscle growth by using a meticulous program design or specific nutrition planning, and even the use of anabolic-androgenic steroids (2). However, to induce physiological adaptations that restructure and remodel muscle tissue, resistance training has been used as the primary instrument (7,9,19,23). In fact, research in recent years has identified mechanical tension as a powerful trigger for hypertrophic adaptations and it quite possibly could be the most important catalyst for muscle growth (15,63,89). Mechanical tension is transduced through mechanotransduction pathways, where mechanical stimuli are converted into intracellular biochemical signalling (41,55,60,72).

Progressive load, a sub-variable of progressive overload, appears to be a potent stimulus for increasing mechanical tension on muscle, and may become even more crucial in the absence of performance-enhancing drugs. Since the rise of anabolic steroids in the 1960s, high-volume pump training became popular and largely replaced the importance of progressive load, further dichotomizing strength and bodybuilding. The prevailing consensus in the literature positions training volume as the primary driver of hypertrophy, with progressive load often regarded as a secondary or sometimes, negligible in its influence. However, enhanced subjects or untrained individuals, whose physiology allows for high-volume adaptations, do not reflect drug free populations, and more specifically the trained drug free populations.

This review challenges that narrative, arguing that for drug free lifters, progressive load and intensity of effort are the most critical variables for sustained hypertrophy, and that the commonly held ‘volume-is-king’ paradigm overstates its importance outside of the pharmacologically enhanced contexts. Despite this ongoing debate, no review to date has systematically contrasted how progressive load and volume operate differently in natural versus enhanced populations. Given that there remains a segment of lifters who aim to build muscle without bodybuilding enhancements, the purpose of this paper is to explore the essential role of progressive load for muscle growth and deliver evidence-based strategies for drug free lifters.

METHODS

This critical review was conducted to explore the significance of mechanical tension and its mechanisms in promoting skeletal muscle hypertrophy, particularly in drug free populations. A structured literature search was performed in PubMed and Scopus to capture the most recent and relevant findings on skeletal muscle hypertrophy in humans. Recent studies were emphasized to highlight current findings, while earlier key studies were included to provide context. Key terms included “natural bodybuilding,” “muscle growth in bodybuilding,” “progressive load strength training,” “progressive overload resistance training,” and “training frequency on muscle hypertrophy,” combined using Boolean operators.

Additional sources were identified through reference mining of included studies, while maintaining inclusion criteria. The **Inclusion Criteria** were: (a) original research, literature reviews or systematic reviews on human skeletal muscle hypertrophy; (b) interventions examining mechanical tension, progressive overload, or training frequency; and (c) English-language publications. The **Exclusion Criteria** were: (a) studies limited to animal models without direct relevance to human muscle adaptation; (b) clinical populations not related to resistance training; and (c) non-peer-reviewed sources.

Titles and abstracts were screened for relevance by a single reviewer (the author, which is appropriate given that this research is a critical review rather than a systematic review), followed by full-text assessment of potentially eligible studies. The data extracted included study design, sample characteristics, interventions, outcomes, and measures of hypertrophy. This methodology was designed to integrate academic rigor with real-world applicability and aims to summarize the role of progressive load in hypertrophy training for non-enhanced bodybuilders.

Also, in addition to synthesizing the results, each included study was qualitatively evaluated for methodological rigor and potential bias. Considerations included sample size, participant training status, intervention duration, operational definitions of muscular failure, and control of training variables. Particular attention was given to common sources of bias in hypertrophy literature, such as the use of untrained participants, lack of blinding, ambiguous failure criteria, and inconsistent load quantification, given that these factors may influence the interpretation of hypertrophic outcomes. This critical appraisal informs the discussion and strengthens the conclusions drawn from the reviewed body of evidence.

CRITICAL ANALYSIS OF THE LITERATURE

Muscle Building Inception

Throughout the first part of the 20th century competitive bodybuilders were the primary demographic who were interested in building muscle and improving aesthetics. At this time, they were focused heavily on strength, compound lifts, and lower set volumes as the gateway stimulus to building a muscular physique. However, by the 1950s and 60s there was a shift in training ideology, and other modalities came to light. Higher "pump" volume training became popular, and many bodybuilders began experimenting with these longer session routines.

Subsequently, in the late 60s and 70s era, there was an even more extreme emphasis on high volume routines, often training twice a day, 6 days a week, with 20 to 30 sets per body part. During this time, the anabolic steroid era was emerging among this demographic, which could very well explain how bodybuilders were able to endure such high volume and frequency routines and still be able to recover and build muscle (3).

However, there was opposition to high volume training and instead, a high intensity training philosophy was introduced. In contrast, this approach featured lower volume and frequency, but significantly higher intensity of effort. This training philosophy was centered on maximal effort, brevity, and gradually increasing strength over a series of workouts to drive muscular development. The theory is that a larger muscle is a direct result of a stronger muscle. These strength training ideas persisted into the 80s and 90s, and even today, many competitive bodybuilders still use these concepts. This relationship between strength and muscle hypertrophy has since been debated.

Strength and Muscle Hypertrophy

In the exercise science literature, strength is defined as the ability to produce force against an external resistance (85). For there to be an increase in strength, an overload stimulus is required (47). Muscle hypertrophy is defined as myofibrillar contractile proteins increasing in size, which can occur by adding sarcomeres in series or parallel to each other (37). It is speculated that there exists a correlation between strength and muscle hypertrophy, suggesting that increasing strength may facilitate muscle growth (48). However, among the various contributing elements, mechanical tension is regarded as the primary driver that initiates changes in muscle architecture and stimulates hypertrophy (50,58,63,71,80,89).

Metabolic stress has also been offered as a potential mechanism to facilitate muscle hypertrophy, where metabolites amplify fiber recruitment and contribute to initiating the mechanotransduction cascade across a greater number of muscle fibers (21). Additionally, muscle damage is a proposed channel in how muscle growth might occur (80). Although, it appears that exercise-induced muscle damage (EIMD) is not needed to bring about muscle growth, though some damage might mediate muscle hypertrophy through signaling pathways, especially during the initial stages of exercise (20,31,81). It seems that both metabolic stress and muscle damage serve as an adjunct when mechanical tension is present, and may have an indirect influence that can result in muscle hypertrophy (89). Although as previously stated, the current literature suggests that mechanical tension is the primary stimulus when the goal is to increase muscle mass (58).

Progressive Overload

Progressive overload is a principle in resistance training programs that commonly focuses on systematic advancement throughout training and is utilized in various ways, including an increase in load, volume, frequency, and other variables (22,34). Since progressive overload can be implemented with such diversification, it can be argued that distinct nomenclature should exist between 'progressive overload' and 'progressive load'. Hence, it is reasonable to propose that progressive load should only be defined as an increase in weight over time, while being absent of all other 'overload' variables.

Progressive load facilitates an important component in a strength training program that is specific for muscle growth, which is the increase in absolute intensity. In resistance training, absolute intensity refers to the amount of weight lifted in relation to an individual's one-repetition maximum (1RM), and it is typically expressed as a percentage of a 1RM (36). For context, lifting 80% of one's 1RM means using a weight that represents 80% of the maximum they can lift for a single repetition. The absolute intensity of a set increases with progressive load, which leads to greater mechanical tension on the muscles. Although, if variables such as body mechanics, tempo, or other subset factors are not held constant, the added load may not translate to increased tension on the muscle. Nonetheless, given that mechanical tension is considered the primary driver of muscle hypertrophy, progressively increasing load over time can be seen as a key strategy to enhance this stimulus and, therefore, facilitate muscle growth.

Intensity of Effort

Intensity of effort, or relative intensity, is another variable that can influence muscle growth (29,30). Intensity can be defined as the momentary effort applied relative to an individual's current ability to produce force during a given set. Therefore, training intensity is often assessed by the proximity to muscular failure. For the scope of this paper, muscular failure is defined as the inability to complete a full concentric repetition despite providing maximal effort (30).

Literature shows that muscular failure, or at least proximal muscular failure, appears to be a valuable exercise stimulus due to the contribution of motor unit recruitment and their fatigue (21,62,92). Motor unit (MU) recruitment is the process by which different motor units are activated to produce a certain level and type of muscle contraction (43,73). According to the Henneman's Size Principle, motor units are recruited based on the force demand placed on muscles, smallest to largest (39,40,74). If a motor unit is turned on, it will activate all the muscle fibers within that motor unit and they will contract to maintain force production (28,74). This allows for both low and high threshold motor unit recruitment within a set, which has been shown to play an important role in muscle growth (29,57,69,92). This recruitment pattern becomes increasingly important as a set moves toward muscular failure, since it can activate the maximum number of muscle fibers. However, full recruitment may very well be at its peak before reaching muscular failure.

One study demonstrated that full spectrum motor engagement typically occurs within the final 3–5 repetitions leading up to concentric failure (86). In addition, Potvin and Fuglevand (66) showed that full motor unit recruitment can take place at approximately 80% of maximum voluntary isometric contraction. This suggests that maximal recruitment can be achieved with loads typically associated with an 8RM, meaning full recruitment can occur with a load that allows for approximately 8 repetitions before concentric muscle failure. Nonetheless, there is a gradation response of motor unit recruitment where type I fibers are initially recruited and then as effort increases, the gradual recruitment of type II fibers occurs. However, if total motor pool recruitment is already maximized at 80% RM loads, then how critical is it to take each set to muscular failure, or at least proximal to stimulate hypertrophy?

A logical inference is that the primary benefit of training to proximal failure lies in the individual muscle fibers' response. While it is not claimed that the last repetitions to muscular failure are exclusively responsible for muscle hypertrophy, they may play the most important role due to contraction velocity and its associated fiber response. Thus, these may be classified as 'stimulatory reps' and could be considered augmented repetitions for muscle growth toward the end of each set. It is proposed that these repetitions may elicit the greatest hypertrophic stimulus due to the increased mechanical tension imposed on each muscle fiber. Forces experienced by individual muscle fibers can be evaluated by their output during various active shortening or lengthening velocities, which is established as the force/velocity curve (27).

The force/velocity curve demonstrates that higher contraction velocities result in reduced force production by individual muscle fibers; whereas, slower velocities enable greater force output and increased mechanical tension (44). This means that even if high-threshold (or low-threshold) motor units are recruited, the induced mechanical tension experienced by the fibers may be lower depending on the contraction velocity (1). As a result, muscle force output depends on the number of actin-myosin cross-bridges formed. When myofilaments slide past each other too quickly, cross-bridge formation is impaired, which leads to diminished force production within the muscle fiber (44). Therefore, when contraction velocities are lower, the recruited fibers are subjected to greater mechanical tensions and vice versa. This relationship introduces the concept of Velocity Under Tension (VUT), which represents an important element in the hypertrophic process.

Even so, muscular failure is hard to quantify and becomes qualitative for each subject. The accuracy of true failure within a set varies based on the subject's experience. One study showed that inexperienced subjects can miscalculate true failure by 4 to 5 repetitions and experienced subjects are able to get closer (84). Additionally, depending on the research, some participants may not have reached true muscular failure, despite claims of "concentric failure". In many cases, sets may have been terminated due to volitional failure, where the subject chose to stop on their own, yet were still classified as reaching true failure. This distinction is important when analyzing hypertrophy research since it can influence the interpretation of training outcomes.

Volume

Increasing set volume is another way to implement overload since it has been shown to increase muscle hypertrophy in some studies (5,77). Volume is commonly defined as the number of sets performed for each muscle group per week (6). Interestingly, there appears to be a dose-response relationship that shows more sets equates to more muscle growth (77,82). However, one point of contention is that many volume-based studies are centered around the intensity of effort. Therefore, it must be questioned how muscular failure is defined and applied to the training subjects, and in addition the demographic chosen to conduct the research.

For instance, the concept of muscular failure varies among researchers, and if true muscular failure is not achieved, higher training volumes may be required to elicit hypertrophic adaptations. Furthermore, exercise selection matters when attempting to navigate a set toward muscular failure. For example, depending on the subject. a barbell squat to failure is almost always vastly different from a machine leg press to failure. The exercise mechanics and complexity of the barbell squat involves various muscle groups, such as the lower back muscles that could fatigue before the larger and stronger prime movers that could potentially limit the mechanical tension stimulus to the targeted muscle groups of the legs (18,54). In fact, if the subject has longer femurs that result in a more inclined torso angle to maintain balance, the load on the lower back and hips is often increased, which fatigues those muscle groups before the quadriceps are fully stimulated. Additionally, the pool of untrained versus trained subjects matters since untrained subjects are usually further away from the failure point and not reliable candidates at assessing the true failure point within a set (70).

In some volume studies, shorter rest intervals are used that can compromise set quality and effort. To provide context, a study by Brigatto et al. (10) showed that 32 weekly sets per muscle group resulted in greater muscle hypertrophy in the lower body when compared to the 24 and 16 set groups. The barbell squat was the multi-joint exercise used for all the groups, and subjects in the higher volume group performed 8 sets for 8 to 10 repetitions to 'concentric failure' on Monday and Thursday but resting only 60 seconds between each set. Given the protocol of 8 sets to concentric failure with only 60 seconds of rest, it is highly unlikely that the subjects were able to achieve true muscular failure in the barbell back squat across all the sets, which suggest the set quality was considerably diminished.

Furthermore, the same group had additional leg extension exercises on Monday and Thursday during which they performed 8 sets to 'concentric failure' that totaled 16 direct sets for the quadriceps for the week. Also, on Tuesday and Friday they performed an additional 16 sets each day on the seated leg curl machine, which totaled 32 direct weekly sets for the hamstrings. Notably, all exercises in this study (i.e., the multi-joint and the single-joint) were performed with 60 second rest intervals. Given the design of this study, its outcomes are open to interpretation. For further perspective, it is valuable to mention that the higher volume group, along with the other groups, had higher total set volumes than reported in the study, since it excluded the seated leg curl volume.

Enes et al. (26) reported similar findings as Brigatto et al. (10). They showed that toward the end of a mesocycle, one group performed up to 52 weekly sets and experienced superior, although marginal hypertrophy outcomes. Nonetheless, it stands to reason that the extremely high volume performed in these studies may have been necessary to compensate for the reduced effort quality per set and thus, could explain why more sets showed superior hypertrophy results. Across these and other studies, additional inconsistencies should be considered beyond just the application of failure, such as rapid repetition speed, exercise selection, and suboptimal mechanics. These factors can further limit the practical relevance of such findings.

It can be argued that when sets are not taken close enough to true muscular failure, repetitions are executed too rapidly, exercise selection is inferior, and/or if exercise form is of poor quality, then mechanical tension on the targeted muscles may be significantly reduced (28,29,46,90). These are various components within a set that can hinder what could be considered an optimal mechanical stimulus and, therefore, the resulting data may fail to represent a true hypertrophic outcome of a properly executed resistance training program. Interestingly, when Fisher et al. (28-30) conducted their research, they used machines to ensure that true muscular failure was achieved in their subjects and found that lower volume routines resulted in similar hypertrophic outcomes when compared to higher volume routines.

The research by Fisher et al. (28-30) infers that if a lower set volume program is comparable to a higher set volume program for hypertrophy, when accounting for the variables outlined, then adding more sets may hinder the subsequent recovery and the adaptation process for muscle growth. Taken together, these factors support the notion that due to individual recovery limitations, training volume reaches a threshold beyond which additional sets may no longer yield net positive returns in muscle hypertrophy (4). That said, the optimal volume appears to vary significantly between individuals, which depends on a range of factors.

Frequency

Regarding muscle hypertrophy, frequency refers to how often a specific muscle group is trained within a given time frame, which is typically over the course of a week (7). A systematic review and meta-analysis showed that as long as weekly volume is equated, the frequency does not matter for muscle hypertrophy (79). However, if set volume needs to increase, then training frequency can be manipulated to influence overall weekly training volume.

Excessive training frequency in concert with high intensity training has been linked to performance drops and a heightened risk of overtraining (33). Since progressive load and intensity of effort appear to be key factors in maximizing muscle hypertrophy, frequency should be carefully considered since muscle growth occurs primarily during recovery periods between sessions, when the net balance between muscle protein synthesis and degradation becomes positive, favoring hypertrophy (64). The literature shows that at least roughly 48 to 72 hours is needed to allow for muscle recovery (59,61).

That said, how fast an individual recovers from a training stimulus is dependent on a host of factors including, but not limited to training experience, volume, intensity, anabolic drugs, gender, emotional, and psychological stress (45,83). Ultimately, recovery timelines are individual and influenced by a host of factors, highlighting the need for personalized programming when determining training frequency.

DISCUSSION

While the fundamental role of mechanical tension in muscle hypertrophy is widely acknowledged, the literature rarely distinguishes how overload principles manifest differently in drug free versus pharmacologically enhanced populations. This point represents a significant gap, given that a lot of the existing research generalizes findings across cohorts without considering the confounding effects of exogenous hormones on recovery, muscle protein synthesis, and volume tolerance, as well as training experience. By critically examining this difference, this review offers a novel synthesis that contextualizes long-standing hypertrophy principles within the specific needs and physiological constraints of natural bodybuilders.

Therefore, the concepts discussed in this paper are: (a) highly relevant to individuals who are not using bodybuilding drugs (e.g., anabolic steroids, SARMs, and peptides); and (b) based on the premise that program design must be more concise for non-enhanced individuals. This distinction is critical because performance-enhancing drugs (PEDs) dramatically alter the body's adaptive response to training. To support this point of view, Bhasin et al. (8) found that supraphysiological doses of testosterone (600 mg/week) caused both hypertrophy and an increase in strength in men who did not undergo any resistance training stimulus. This shows the potency of anabolic steroids and their role in muscle hypertrophy and strength, independent of exercise. That said, the foundational principles like "progressive load" may not hold the same level of physiological importance in pharmacologically enhanced individuals. While this principle can be effective across the board for everyone, it is especially relevant to natural, non-enhanced individuals.

Optimizing Hypertrophy

The goal is to understand how to optimize muscle hypertrophy in the absence of drug use by using key variables that work synergistically to maximize mechanical tension, which is the key driver for muscle growth. We know that mechanical tension is probably the central mechanism to stimulate an adaptive response where the muscle fibers become stronger and larger. Thus, to continually generate higher levels of tension, progressive load must occur by gradually increasing the resistance placed on the muscles.

In addition to progressive load, training must be performed with sufficient intensity to progressively recruit all motor units, but also to maximize the mechanical tension experienced by the individual muscle fibers. Subsequently, the training volume must be sufficient to accumulate tension that is tailored to individual recovery capacity to avoid diminishing returns. Following the training stimulus, there must be a sufficient rest period between the sessions to allow for recovery and adaptation.

This strategy, as previously mentioned, may be a better option for subjects who do not use performance enhancing drugs (PEDs). In theory, enhanced subjects taking exogenous anabolic drugs do not need to focus on strength, since the internal hormonal milieu is oriented towards muscle anabolism and thus, making nearly any mechanical tension sufficient to drive adaptation (3,8,42). These sequential training principles are illustrated in Figure 1, which present a conceptual framework for maximizing hypertrophy in non-enhanced populations.

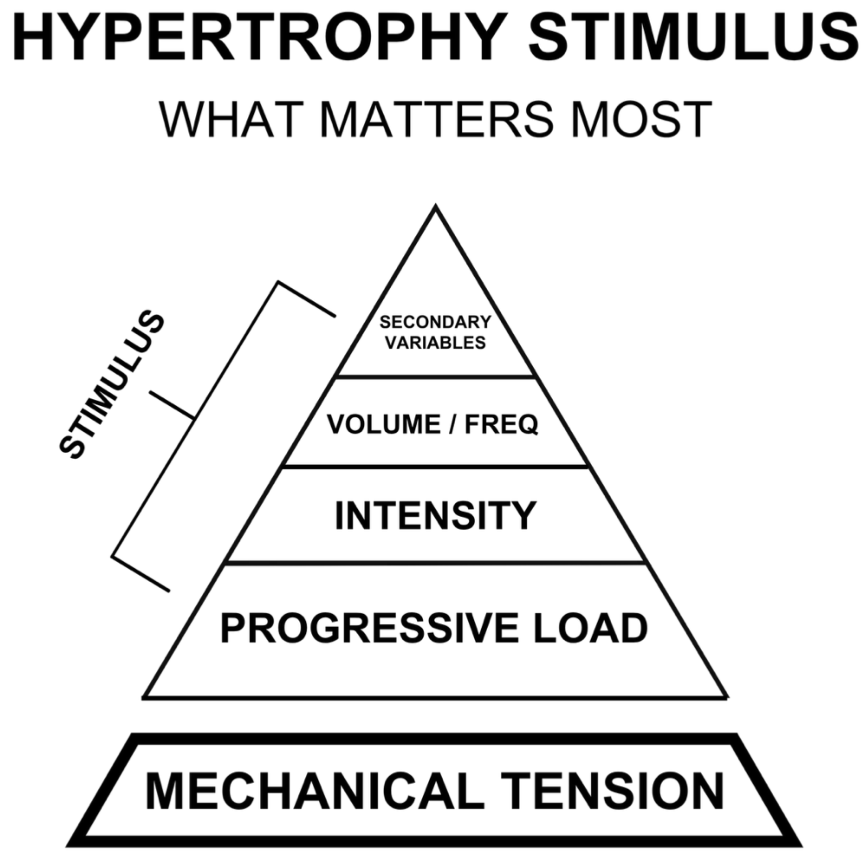

Figure 1. Conceptual Model of Hypertrophy Stimulus Hierarchy.

Progressive Load

Mechanical tension mediates muscle hypertrophy. But stated more precisely, progressive mechanical tension is the true mediator of continued hypertrophic adaptations (32,50,63). Strength development forms the basis of mechanical tension, while other training variables work in unison to accumulate this tension to stimulate muscle growth. Therefore, it can be argued that the focus should be on progressive loading within anaerobic glycolytic repetition ranges, as research has shown that a wide range of loads in this energy system can effectively promote muscle hypertrophy (52,53,75,76).

Hence it is postulated that increasing strength, in bodybuilding-specific repetition ranges (i.e., 6 to 30 repetitions), covers a physiological base that can induce optimal muscle hypertrophy. While it remains debated whether strength or hypertrophy comes first, there appears to be a feedback loop in which one supports and reinforces the other. That said, there are situations where increasing load can become difficult, in which case progressive repping with the same load can be implemented. Plotkin et al. (65) demonstrated that during transient mesocycles, this progressive strategy can yield comparable muscle hypertrophy outcomes. This allows steadier increases in load over time, which facilitates musculoskeletal adaptations and supports hypertrophic gains (65).

Intensity
High intensity effort, such as approaching muscular failure, seems to be another important role in stimulating muscle hypertrophy (13,25,28,29,92). On the other hand, some research shows that muscular failure does not appear to be necessary for increasing muscle hypertrophy, while other research shows non-linear relationships between proximity to muscular failure and hypertrophy, suggesting that this may not be the best way to train (35,68,69).

However, a key importance may lie in the relationship between contraction velocity and fiber force production, and potentially fiber recruitment. This may lead to a greater number of 'stimulatory reps' experienced by the muscles which can affect muscle growth. Ultimately, mechanical tension at the fiber level depends not only on motor unit activity but also the velocity of muscle contraction. Therefore, the Velocity Under Tension (VUT) can appear to play a significant role in how individual muscle fibers experience external forces and their subsequent hypertrophic response.

Since proximal failure training physiologically imposes slower contraction velocities, it is reasonable to conclude that this, combined with progressive loading, may produce maximal hypertrophic adaptations. One way to gauge proximity to muscular failure is by utilizing the Reps in Reserve (RIR) model. This model is a simple strategy to determine "how many more reps can be performed before positive [concentric] failure", and serves as the most robust scale to determine muscle failure proximity (38). Generally, a useful way to estimate how many repetitions remain before reaching muscular failure is by observing a noticeable slowdown in repetition speed. It has been postulated that once this deceleration begins, approximately 3 to 5 repetitions remain before true failure occurs.

With that said, velocity and muscular failure do have an inverse relationship. In practice, repetitions are often executed at higher velocities distal to failure. This mode of training has been popularized by professional bodybuilders and in other modalities, such as Crossfit and Olympic lifting. However, given that muscle fibers experience greater forces under slower contraction velocities, controlled repetitions, even outside of muscular failure, may provide more effective mechanical tension on the muscles (27).

Furthermore, research has shown that the integration of slower eccentric movements that prolong the duration of the negative phase is considered a key factor in promoting muscular hypertrophy (14,51). It appears that there is enhanced force production during the eccentric phase, which can be attributed to either an increase in force per cross-bridge, an increase in cross-bridging actions, or both (12,56,67).

Conversely, accelerated velocities amplify peak forces that can propagate through joints and connective structures that potentially can increase the risk of injury (11,24,29). Moreover, explosive lifts may result in reduced muscle fiber stimulation due to the momentum, which can attenuate muscular loading through a full range of motion and mitigate their effectiveness for enhancing muscle growth (29,46,90).

Volume
However, even with the aforementioned considerations, sufficient training volume does appear to be a factor in optimizing muscle hypertrophy and can be used as a tool for growth (82,77,78). Some literature suggests staying between 12 to 20 sets per muscle group (per week) to

maximize hypertrophy (5,49). However as previously mentioned, the relative intensity applied in studies is subjective among both the subjects and the instructors. Higher volume output accompanies lower intensity output and thus, they are inversely related.

Nonetheless, a systematic review and meta-analysis does show that set volume has a graded dose-response relationship with muscle hypertrophy (77). Conversely however, other research has shown lower volume protocols can be just as effective for muscle growth and strength development (16,17,29,91). Furthermore, as previously noted, recent research may have overstated the role of high volume in muscle growth, potentially overlooking critical variables and other nuanced training parameters that are not always accounted for or neglected.

Additionally, much of the existing literature is acute by nature (<12 weeks) rather than longitudinal, meaning it examines short-term responses rather than long-term adaptations that may limit the applicability of the findings when compared to real-world settings over time. Ultimately, it can be suggested that if subjects are not producing high enough effort, they may need more volume to compensate for intensity adverse sessions or what is considered lower intensity training.

Moreover, anabolic steroids and similar substances significantly enhance recovery capacity that allow users to tolerate much higher volumes than natural counterparts and still increase muscle mass (88). This highlights why progressive load (and intensity) may hold greater significance than volume for sustained hypertrophy in drug free individuals, given that a correlation has been observed between strength and hypertrophy (87). However, it is speculation as to which comes first, strength or hypertrophy?

Without progressive load, volume is ultimately negated through diminishing returns since there is a clear ceiling as to how much volume can drive further adaptation. In contrast, strength can be progressively developed over many years, continually providing a novel stimulus for muscle growth. It must be noted, however, that both volume and strength capacity are finite, although volume often reaches its ceiling more quickly due to recovery demands, positioning progressive loading as the more practical and sustainable long-term strategy for hypertrophy. Therefore, the focus on adding set volume in lieu of load progressions may obscure true progression over time, since set volume can become an artificial means of progression.

Frequency

Frequency of stimulation or how often between the next exercise session for the same muscle group should be hedged against the volume of work. Training volume and frequency are inversely related, such that a higher volume often necessitates a lower frequency to allow for adequate recovery and vice versa. There must be sufficient time between sessions for full recovery and adaptation to enable muscle hypertrophy to occur. Although it is hard to quantify this number as it is predicated on various factors. Like volume, frequency can be treated as a conservative variable to allow for adequate recovery and promote hypertrophic adaptations. Re-stimulating the muscle tissue too soon can hinder the recovery-adaptation process and halt the progress, especially if the volume demands are exceedingly high. There should exist a balance between intensity, volume, and frequency – the foundational principles.

Evidence Limitations

It is also important to interpret the existing findings in regards to the methodological limitations and potential biases within the literature. A significant proportion of hypertrophy studies rely on untrained participants, whose rapid early adaptations may overstate the effects of volume or diminish the apparent importance of progressive loading. In addition, inconsistent definitions of muscular failure, insufficient reporting of actual effort levels, and the lack of control over movement tempo introduce variability that can obscure mechanistic conclusions.

These methodological factors may partly explain conflicting findings and highlight the need for more rigorously controlled research, particularly in trained natural populations to clarify the relative contributions of load progression, effort, and volume. These variables interact differently in drug free environments when compared to enhanced environments as illustrated in Table 1. The differences between natural and enhanced training have important implications for program design and hypertrophic potential.

Table 1. Comparison of Training Variable Emphasis in Natural vs. Enhanced Lifters.

Training Variables	Drug Free Population	Enhanced Population	Implications for Natural Lifters
Progressive Load	More critical due to limited anabolic environment	Less critical due to anabolic environment	Should be prioritized to drive long-term growth
Training Set Volume	Limited by recovery capacity	Higher recovery capacity	Should be adjusted to optimize results
Intensity of Effort	Critical for motor unit recruitment and fiber tension	Still beneficial but less consequential	Should remain a focal point for growth
Frequency of Stimulation	Longer recovery due to natural hormonal environment	Shorter recovery due to exogenous hormonal environment	Should be adjusted to match recovery capacity

PRACTICAL APPLICATIONS

As summarized in Table 1, to maximize muscle hypertrophy for non-enhanced individuals, training should emphasize progressive load as the foundation of mechanical tension. It is advised to work within a 6 to 30 rep range when implementing progressive load. However, when stalls occur, progressing with reps with the same load is recommended since this can further sustain muscular growth adaptations. Additionally, training proximal to muscular failure is essential, given that it maximizes motor unit recruitment and slows contraction velocity, which increases muscle fiber tension.

The Reps in Reserve (RIR) model helps gauge proximity to failure, with 1–2 RIR advised for most sets and 0 RIR (true failure) used more selectively. Furthermore, even though velocity slows involuntarily when sets are taken close to failure, it is still recommended that for all preceding repetitions, both concentric (positive phase) and eccentric (negative phase) muscle actions are performed under controlled, non-ballistic conditions for optimal tension loading. Set volume should support the mechanical tension stimulus, starting around 5 sets per muscle group per week and adjusted (> or <) based on individual response. The frequency stimulation of muscle groups should allow enough recovery to avoid interfering with adaptations, giving at least 48 hours but can span up to 7 days depending on a variety of factors.

Therefore, maximizing growth is best implemented in the following order: (A) consistent load progression, (B) high training effort, (C) sufficient set volume, and (D) enough recovery between sessions, all of which supports sustainable hypertrophy. Considering all facets, progressive load and intensity of effort are synergistic and remains the most reliable strategy to impose mechanical tension over time, and thus, maximizing muscle hypertrophy. In closing, if strength and effort were not essential components for muscle hypertrophy, and instead, volume was the driving mechanism, a greater percentage of natural, well-developed physiques would be far more common than what is observed. By reframing muscle hypertrophy programming around progressive load and intensity of effort instead of volume, this review provides a corrective lens for both research design and real-world training practices for natural lifters.

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Training Effects of Qigong Combined with Muay Thai on Lipid Biomarkers in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial

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[1]Exercise and Sport Sciences Program, Khon Kaen University, Khon Kaen, Thailand, [2]Henan Kaifeng College of Science Technology and Communication, Kai Feng, China, [3]Faculty of management sciences and information technology, Nakhonphanom University, Nakhonphanom 48000, Thailand, [4]Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand, [5]Exercise and Sport Sciences Development and Research Group, Khon Kaen University, Khon Kaen 40002, Thailand, [6]Faculty of Public Health, Mahasarakham University, Mahasarakham 44150, Thailand

ABSTRACT

Hao Gao, Narisara Premsri, Guang Yang, Orathai Tunkamnerdthai, Apiwan Manimmanakorn, Terdthai Tong-Un, Rujira Nonsa-ard, Ploypailin Aneknan, Naruemon Leelayuwat. The purpose of this study was to investigate the training effects of Khon Kaen Qigong (KKQ) on lipid biomarkers in older adults with mild cognitive impairment before and after 12-week intervention that consisted of a 60-minute KKQ/day, 3 days/week, for the Exercise Group and no KKQ intervention for the Sedentary Control Group. The data were analyzed using ANCOVA. The findings indicate that the subjects in the KKQ Exercise Group improved their lipid metabolism with a decrease in subcutaneous and total fat mass of the lower limbs and blood biomarkers that included triacylglycerol and total cholesterol concentrations independent of their improvement in cognition. Together with no exercise injuries, the findings suggest that the KKQ training has the potential to be recommended to decrease cardiovascular disease risk factors in older patients with mild cognitive impairment.

Key Words: Adiposity, Aging, Cognition, Exercise

INTRODUCTION

This study is multisystem research on Khon Kaen Qigong (KKQ) combining Qigong (Baduanjin and Wuqinxi) with Muay Thai (Wai Khru, a warming up part) in sedentary older adults with mild cognitive impairment (MCI). The effects of this intervention on metabolism, neurological, musculoskeletal, and cardiorespiratory systems were explored. Recently, we published that the KKQ training improved cognition in this population (45). Regarding a link between cognition and metabolic biomarkers, such as body composition and blood biomarkers (4,19,48), KKQ may have beneficial effects on markers that are related to cardiovascular disease (CVD) risk mortality (29). Thus, this study is important for providing knowledge of exercise intervention that reduces CVD risk mortality for patients with MCI.

The global prevalence rate of MCI is 15.6% and increases with age (5). It is not just a transitional phase between normal cognitive aging and dementia, but is a crucial period for enforcing interventions (22). Besides, the elderly often experienced a decrease in metabolic capacity, which can lead to many metabolic diseases, such as obesity, diabetes, hypertension, dyslipidemia, and metabolic syndrome (6,37). Accordingly, the alarming growth of the MCI prevalence rate increased detrimental evidence on the metabolism of the elderly with MCI and exacerbates the burden on both families and the healthcare system.

Regarding the impaired metabolism, the link between cognitive function and body composition is still unclear. A higher MCI risk was shown to be associated with loss of muscle mass in lower limbs in those participants (4). In contrast, the other did not find this association in these participants. Furthermore, cognition was not associated with fat tissue in specific areas, such as subcutaneous and visceral fat tissues (38). However, it is worth exploring the link in the group of population.

In addition, metabolic markers in the blood, such as glucose (FBG), glycated haemoglobin A1c (HbA1c), triacylglycerol (TG), and high-density lipoprotein cholesterol (HDL-c) are correlated with cognition in elderly participants with MCI (33) and type 2 diabetes (19,48). Accordingly, interventions improving cognition may also be found with improved metabolic markers. Recently, KKQ training has been reported to improve cognition in older adults with MCI (45).

To our knowledge, two components of KKQ, Baduanjin and Wuqinxi Qigong, have been reviewed and shown to yield beneficial effects on body composition and blood markers. Both types of Qigong were shown to improve body composition, such as total body mass and body fat mass, (44,47) and blood markers, such as TG, low-density lipoprotein (LDL-c), and HDL-c (7,18,40,49). However, no research on the effects of Muay Thai on these markers are reported in the research literature.

Regarding a link between cognition and metabolic biomarkers, such as body composition and blood biomarkers (4,19,48) and the potential effect of KKQ on cognition, KKQ may have beneficial effects on the markers that are related to cardiovascular disease risk mortality (29). If so, then finding such results would be important in providing an alternative exercise intervention to decrease CVD risk mortality in patients with MCI. Hence, the primary purpose of this study is to reveal the training effect of KKQ on specific and whole-body composition compartments as well as the effect on blood metabolic biomarkers. Also, the correlations between the changes in the biomarkers and cognition need to be better understood.

METHODS

Research Design

This study is a randomized controlled trial with pre- and post-assessments, following the CONSORT reporting guidelines for parallel group randomized trials (36).

Participants

From June 2021 to February 2022, the participants were 60 to 75 years of age who were recruited from the Khon Kaen province, Thailand. Physical examinations, electrocardiogram, health questionnaires, and blood biochemistry were used to screen the participants. The questionnaire featured health-related inquiries and the Physical Activity Readiness Questions (PAR-Q) assessed their ability to engage in physical activity. The participants with a Montreal Cognitive Assessment (MoCA) score below 26 that indicates MCI were selected.

The participants involved in this study were physically inactive and had no underlying diseases, such as cardiovascular, renal, liver, respiratory, orthopedic diseases, or chronic infections that could impact their ability to exercise. However, participants with irregular blood pressure, blood glucose, and lipid profile who were able to effectively maintain their medications were included. Also, the participants who did not have at least 2 years of experience with consistent exercise, meditation, yoga, Muay Thai, or Qigong were included. The criteria for exclusion consisted of cognitive impairment resulting from other causes and/or medical conditions that rendered exercise unsafe and, therefore, would prevent the person from exercising or having participated in other studies that may have influenced this research.

The process of recruiting involved placing advertisements on Khon Kaen University platforms, Facebook.com, and utilizing word-of-mouth among the university and nearby community. The test site was set up at the Nutrition and Exercise Laboratory of Faculty of Medicine, Khon Kaen University, Thailand.

This study was approved by the Ethics Committee of Khon Kaen University (HE641163 on June 8, 2021) following the Helsinki Declaration. The registration number TCTR20211228001 was issued on December 28, 2021 by the Thai Clinical Trials Registry. The participants were given a thorough explanation, both orally and in writing, before giving their consent to participate in the study. They were also informed that they could withdraw from the experiment at any time.

Power Calculation

The sample size was calculated based on improvement in body fat mass by using G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) based on study by Yang et al. (44). Power was set at 80%, alpha at 5%, and Cohen's effect size at 0.50. The sample size for each group was 20 participants and the dropout rate was 20%.

Randomization and Blinding

The computer-generated random sequence was assigned by using the research random generator. The participants who met the criteria were randomly divided into 2 Groups based on a 1:1 ratio, which included the KKQ Group and the Control Group (CG). The codes were in the same size and color opaque envelopes. All the researchers were blinded to the codes until the study was completed.

Research Protocol

The research protocol is shown in Figure 1. Two days before each visit, the participants abstained from high-intensity exercise. On every visit, they arrived at the laboratory at 8 a.m. after fasting overnight. During the experimental period, the participants were forbidden to drink alcohol, smoke, and participate in strenuous exercise. Room temperature and humidity were kept comfortable and constant throughout the experiment.

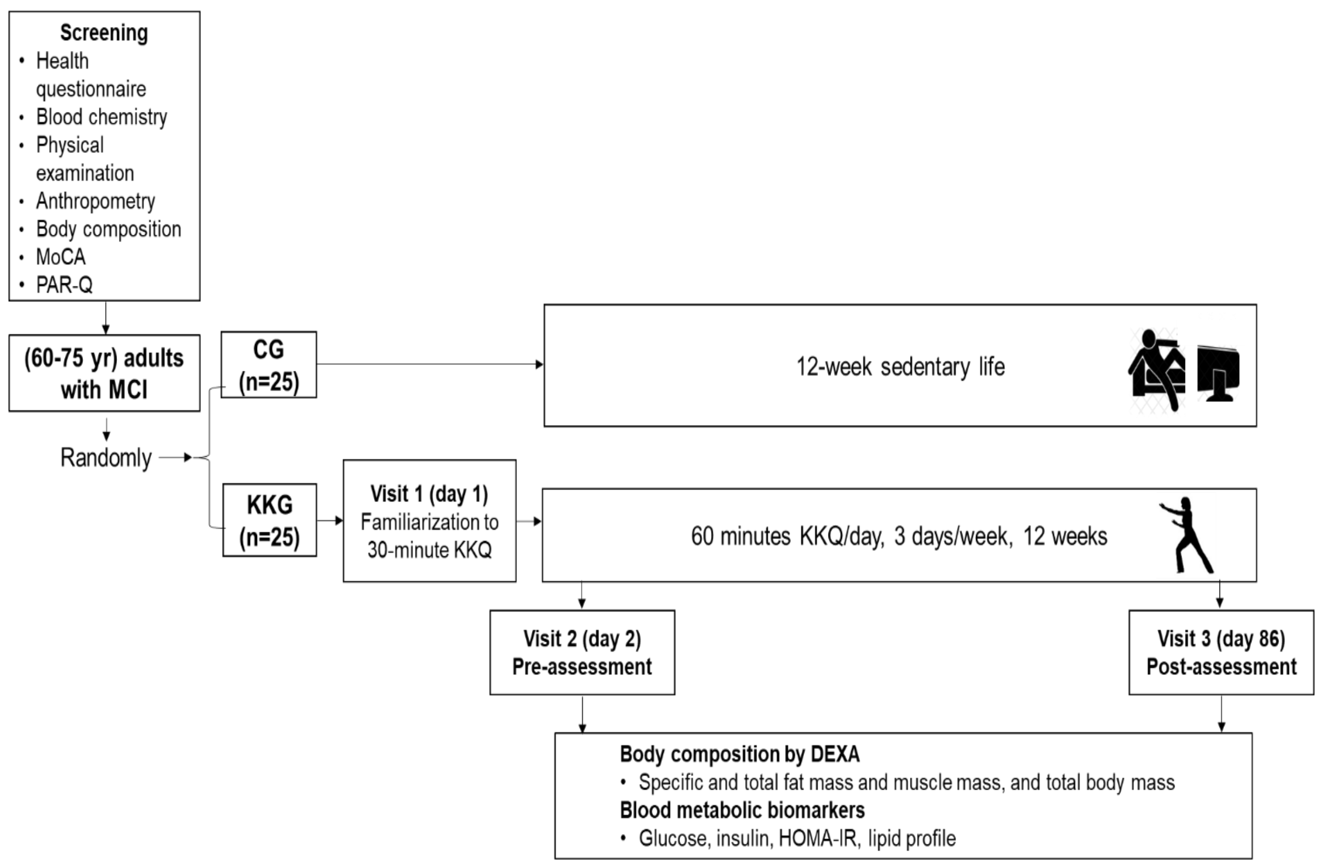

Figure 1. Protocol of this Study. MoCA: Montreal Cognitive Assessment, **PAR-Q**: Physical Activity Readiness Questions, **MCI**: Mild Cognitive Impairment, **CG**: Control Group, **KKG**: Khon Kaen Qigong Group, **KKQ**: Khon Kaen Qigong, **DEXA**: Dual-Energy X-Ray Absorptiometry, **HOMA-IR**: Homeostatic Model Assessment for Insulin Resistance.

KKG

The participants visited the laboratory 3 times. During the first visit (day 1), they performed a 30-minute KKQ exercise (45) to familiarize themselves with the movements and procedures.

During the second (day 2) and third (day 86) visits, which were conducted under similar conditions, the participants arrived at the laboratory and rested in a supine position for 15 minutes until vital sign was stable. Then, blood samples were collected from the antecubital vein using a vacuum blood collection system (BD Vacutainer®, NJ, USA) to analyze fasting plasma glucose (FPG), insulin, HbA1c, total cholesterol (TC), TG, HDL-c, and LDL-c.

Homeostasis model assessment for insulin resistance (HOMA-IR) was calculated from FPG and insulin (26). Following the blood sample collection, the participants went to the Department of Radiology at Srinagarind Hospital to measure body composition by Dual-energy X-ray absorptiometry (DEXA).

After the second visit, the participants engaged in 60-minute daily KKQ training sessions 3 times per week for 12 weeks as a Group activity in their community. On the third visit, after 12 weeks of intervention, the same procedures were repeated. The participants were asked about any discomfort or injury during the exercise familiarization and the training period.

Quality Control of KKQ Training

All the participants wore comfortable flat shoes and sportswear. For 12 weeks, all the participants received forms to record their exercise training and injuries (45). They returned the records on the third visit. During the exercise assessment and training, a certified KKQ leader guided and corrected their movements. They were asked to move correctly with pursed lip breathing during the KKQ practice. Every week, the researchers phoned the participants to remind them to maintain their dietary intake, attend the practice sessions, and not to do any other exercises except KKQ.

Controls Group (CG)

The CG participants visited the laboratory twice to perform similar to the second and third visits of the KKG. They were instructed to maintain their sedentary lifestyle and abstain from any structured exercise during the 12-week study period. After passing the screening, all the participants received 3-day (two working days and one weekend day) dietary and physical activity records to analyze daily energy intake and expenditure for 1 week before pre- and post-assessment visits. Then, they returned both forms to the researcher on both visits.

Outcome Measurements

Body Composition

DEXA (LUNAR, GE Medical Systems, Madison, WI, USA) was used to determine body composition, including fat mass, lean mass, and total body mass. During the measurement, the participants wore light indoor clothing and lay supine without any movement for a few minutes. The machine was calibrated prior to every measurement.

Blood Metabolic Biomarkers

In a supine position, 10 mL of blood was drawn from the antecubital veins. The collected blood samples were immediately separated into three tubes: 1 mL blood in a sodium fluoride tube to measure glucose concentration; 7 mL blood in ethylenediaminetetraacetic acid (EDTA) tube to measure lipid profile and HbA1c concentrations; 2 mL blood in a gel and clot activator tube to measure the insulin concentration. All the tubes were then centrifuged at 3000×g (TOMY-CAX-370, Tokyo, Japan) for 10 minutes at 4°C. The upper layer was then immediately transferred into aliquots, which were frozen at −80 °C until their analysis.

A glucose analyzer (YSI 2300 STAT Plus™, Yellow Springs, OH, USA) using an enzyme-based biosensor was used to measure glucose. The analyzer pumped a 25 μL sample from a sodium fluoride tube (Greiner Bio-One Ltd., Chonburi, Thailand) and then diffused through the membrane. The membrane contained an immobilized glucose oxidase enzyme that was rapidly oxidized, producing hydrogen peroxide. The produced hydrogen peroxide was in turn oxidized at the platinum anode, producing electrons. The electron flow was directly proportional to the steady-state hydrogen peroxide concentration and, therefore, to the FPG concentration.

Plasma HbA1c was analyzed by an immuno-turbidimetric inhibition assay at the Biochemistry Laboratory of the Srinagarind Hospital, Faculty of Medicine, Khon Kaen University, Thailand. Serum insulin concentrations were assayed with a radioimmunoassay kit (MP Biomedical GmbH, Eschwege, Germany) at the Srinagarind Hospital. FPG and insulin concentrations were then used to calculate the HOMA-IR

(26).

Plasma TG, HDL-c, and TC concentrations were analyzed using the glycerol phosphate oxidase-phenol 4-aminoantipyrine peroxidase (GPO-PAP) method, the homogeneous HDL-c plus method, and the cholesterol oxidase-peroxidase method, respectively (Reflotron®Plus, Boehringer Mannheim, Mannheim, Germany). The machine was calibrated daily. The LDL-c concentrations were calculated using the Friedewald formula (12). All machines were calibrated before all analysis and blood samples were duplicated in every measurement.

Statistical Analysis

The data are presented as mean ± standard deviation (SD) or median (interquartile range, IQR). The normality of the distribution of data sets was tested using a Kolmogorov-Smirnov Test. If the data had a non-normal distribution the difference was tested by Man-Whitney U Test. If the data had a normal distribution, the difference was tested by ANCOVA, which compares the data at post-assessment adjusting by those at pre-assessment. A two-sided test was used in this study. Pearson correlation coefficient was used to analyze normally distributed data and the Spearman correlation coefficient was used to analyze non-normally distributed data. Values of $P < 0.05$ were considered statistically significant. Statistical analysis was performed using SPSS 24.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The Consort flow diagram of the study is shown in Guang et al. (45). Of the 60 participants, 50 participants were recruited. Ten participants were not recruited because their MoCA score was 26 or above. Then, the 50 participants were randomly allocated into 2 Groups, and 45 participants completed the 12-week experiment (CG: n = 23, 1 male and 22 females; KKG: n = 22, 1 male and 21 females). Two and 3 female participants in the CG and the KKG, respectively, withdrew from the experiment because of medical problem. Average adherence of participants of both groups to KKQ training was 93%. The average room humidity and temperature were 59.4 ± 4.7% and 24.9 ± 0.9°C respectively throughout the study. Importantly, no participants complained of having an injury either during or after the exercise session throughout the study.

Characteristics of the Participants

Both groups had similar baseline characteristics except for a higher MoCA in the CG than in the KKG. Furthermore, in the KKG, 16 people were overweight (15 females, 1 male) and one was obese (female). In the CG, 14 women were overweight, and one was obese, all of them were females. At pre-assessment, there were no significant differences between the groups in blood chemistry parameters including FPG, insulin, HOMA-IR, and lipid profile (45).

Effects of Intervention on Body Composition

Compared with the CG, subcutaneous, percentage, and total fat mass of both lower limbs, and total body mass of the KKG were lower (all $P < 0.05$, Table 1). Compared with pre-assessment, KKG had decreased subcutaneous and percentage of fat of left leg, total fat mass of both legs, and trunk mass at post-assessment. KKQ also increased lean mass of the left leg (all $P < 0.05$, Table 1). Whereas the CG showed an increased percentage of fat in the left leg and increased lean mass in the right arm (all $P < 0.05$, Table 1) without any difference from the KKG. However, there were no significant differences in other body composition parameters within and between the 2 Groups after 12 weeks (Table 1).

Effects of Intervention on Blood Metabolic Biomarkers

After 12 weeks, the KKG exhibited lower plasma TC and TG concentrations than those in the CG (both $P < 0.05$, Table 2). There were no significant differences in other blood biomarkers between the 2 Groups. Furthermore, compared with pre-assessment the KKG had decreased plasma TG concentration, while the CG had increased HDL-c/LDL-c (all $P < 0.05$, Table 2).

Correlation between MoCA Scores and Metabolic Biomarkers

No correlation between the MoCA score and body composition ($P > 0.05$, Table 3) and blood metabolic biomarkers ($P > 0.05$, Table 4) before and after training was found.

DISCUSSION

This study is the first to explore whether KKQ training improves specific and whole-body composition and blood metabolic biomarkers in older adults with MCI. Regarding the link between metabolic parameters and cognition, the results of this study may mediate the impact of KKQ training on the improvement of cognition in this Group of participants (45). The findings of this study show the potential effects of the KKQ training on decreased subcutaneous, percentage, and total fat mass of both lower limbs, total body mass, and plasma TC and TG concentrations. However, the results of KKQ-induced reduction of the variables were not related to improvement of cognition.

The reduction in fat compartments according to training supports our main hypothesis. This can be explained by the intensity and movements pattern of KKQ. The exercise intensity of KKQ is very low level (46) which the active muscle utilizes highest fat compared with other levels (16,32). This is comparable with our laboratory which found that the training of KKQ increased whole-body fat oxidation rate and total energy utilization during the KKQ practice [unpublished data]. In this study, the increased energy used from fat may reduce fat accumulation, leading to decreased fat composition after training. Interestingly, we provided new information on specific fat compartments of both lower limbs that is attenuated by the training. This is reasonable because both limbs carried and moved the entire body weight throughout the practice. Furthermore, it has been known that obesity is one of the cardiovascular risk factors (41). Taken together, KKQ training has benefits on improving cardiovascular disease risk factors via the fat mass reduction.

Table 1. Body Composition Measured by Dual-energy X-Ray Absorptiometry (DEXA) at Pre- and Post-Assessment in Both Groups.

	CG (n = 23)		P-value a	**KKG** (n = 22)		P-value b	P-value c	MD [95% CI]	P-value d
	Pre	Post		Pre	Post				
				Fat Mass (%)					
Head	24.3 (24.1-24.4)	24.3±0.35	0.200	24.2 (24.1-24.5)	24.2±0.58	0.300	0.310	0.03（-0.3,0.3）	0.461
L Arm	36.3±7.70	36.8±7.96	0.060	39.0±5.57	37.8±5.19	0.080	0.290	-0.1（-0.5,0.3）	0.087
R Arm	37±7.49	36.6±7.23	0.100	39.8±5.97	40±5.74	0.100	0.340	-0.3（-0.4,0.4）	0.188
Trunk	32.5±5.58	32.6±5.85	0.200	35.9 (29.7-37.2)	33.1±4.19	0.200	0.390	-0.05（-0.3,0.3）	0.463
L Leg	35.8±5.96	38.6 (34.4-39.4)	**0.040**	38.7±4.29	36.2±3.88	**0.030**	0.240	0.23（-0.8,0.2）	**0.043**
R Leg	37 (33.4-40)	36.8±5.88	0.150	39.3±4.40	35±3.80	0.100	0.270	-0.2（-0.7,-0.1）	**0.049**
Subtotal	34.2±5.47	34.5±5.80	0.080	36.2±4.11	35.8±3.69	0.060	0.290	-0.2（-0.6,0.4）	0.297
Total	33.6±5.00	33.8±5.28	0.100	35.4±3.84	34.9±3.52	0.080	0.290	-0.1（-0.5,0.3）	0.150
				Subcutaneous Fat Mass (kg)					
Arms	46.1 (44.7-48.3)	45.8 (44.5-49.0)	0.100	47.9 (45.0-49.8)	48±4.11	0.080	0.400	-0.9 (-1,1)	0.179
Legs	37.6 (34.9-41.9)	37.9±5.68	0.060	39.9±4.82	34.5±4.82	**0.030**	0.250	-2.7 (-4,-1)	**0.017**
Trunk	26.2 (24.9-28.7)	26±4.31	0.150	27.6±3.87	28.1±3.64	0.100	0.350	-0.25（-1.5,1）	0.205
Whole Body	29.2±4.96	29.0±4.68	0.200	30.7±4.13	32.1±5.06	0.100	0.300	-0.5（-2,1）	0.072
				Fat Mass (kg)					
Head	1.02±0.13	1.00±0.12	0.200	1.04±0.10	1.03±0.09	0.300	0.290	-0.03（-0.3,0.3）	0.141
L Arm	1.14±0.41	1.24 (33.5-44.2)	0.050	1.15 (36.4-43.6)	1.19±0.29	0.060	0.340	0.04（-0.2,0.2）	0.531
R Arm	1.24±0.40	1.26±0.42	0.100	1.36±0.36	1.36±0.30	0.100	0.390	-0.1（-0.2,0.2）	0.190
Trunk	9.34±3.06	9.23±3.05	0.200	9.74±2.46	9.49±2.49	0.100	0.290	-0.16（-0.5,0.3）	0.261
L Leg	3.28±0.99	3.35±1.03	0.150	3.79±0.87	3.15±0.82	**0.030**	0.240	0.2（-0.8,-0.2）	**0.038**
R Leg	3.43±0.95	3.34±1.24	0.200	3.88±0.90	3.15±0.96	**0.040**	0.270	0.15（-0.7,-0.1）	**0.026**

	CG (n = 23)		P-value a	KKG (n = 22)		P-value b	P-value c	MD [95% CI]	P-value d
	Pre	Post		Pre	Post				
Subtotal	18.4±5.49	18.4±5.66	0.100	20.0±4.40	19.6±4.21	0.060	0.310	-0.2 (-0.6,0.4)	0.266
Total	18.6±6.67	19.3±5.63	0.080	21.0±4.47	20.7±4.27	0.070	0.290	-0.2 (-0.5,0.3)	0.355
Lean Body Mass (kg)									
Head	2.69±0.33	2.69±0.33	0.300	2.73±0.24	2.72±0.22	0.200	0.290	-0.03 (-0.3,0.3)	0.176
L Arm	1.88±0.53	1.86±0.38	0.200	1.68 (1.49-1.93)	1.75 (1.66-2.02)	0.150	0.340	0.05 (-0.3,0.3)	0.150
R Arm	1.87 (1.57-2.40)	2.04±0.43	**0.040**	1.83 (1.62-2.08)	1.80 (1.68-2.10)	0.050	0.390	0.24 (-0.4,0.4)	0.425
Trunk	18.6±3.45	18.2±3.48	0.100	18.0 (17.3-19.9)	18.5±3.01	0.060	0.290	-0.27 (-0.5,0.3)	0.152
L Leg	5.52±1.13	5.46±1.04	0.100	5.48 (5.03-6.08)	5.72±0.86	**0.040**	0.240	-0.26 (-0.4,0.2)	0.086
R Leg	5.59±1.17	5.59±1.15	0.200	5.53 (5.06-5.94)	5.74±0.91	0.050	0.270	0.25 (-0.5,0.1)	0.117
Subtotal	33.7±6.59	33.2±6.36	0.060	32.4 (28.1-39.9)	33.7±5.19	0.070	0.310	-0.23 (-0.6,0.4)	0.115
Total	36.2±6.71	35.8±6.44	0.080	35.0 (33.3-38.4)	36.4±5.33	0.060	0.290	-0.2 (-0.5,0.3)	0.211
Total Mass (kg)									
Head	4.16±0.53	4.17±0.50	0.300	4.27±0.37	4.25±0.33	0.200	0.290	0.02 (-0.3,0.3)	0.199
L Arm	3.12±0.77	3.14±0.66	0.200	2.92 (2.70-3.48)	3.12±0.54	0.200	0.340	0.02 (-0.3,0.3)	0.274
R Arm	3.35±0.77	3.40±0.70	0.100	3.18 (2.90-3.86)	3.41±0.56	0.100	0.390	-0.01 (-0.3,0.3)	0.261
Trunk	28.2±5.90	27.8±5.85	0.060	28.8±5.05	27.2 (23.9-31.8)	**0.040**	0.290	0.56 (-0.8,-0.2)	0.637
L Leg	9.08±1.89	9.08±1.81	0.200	9.73±1.57	9.76±1.53	0.100	0.240	-0.03 (-0.4,0.2)	0.142
R Leg	9.29±1.84	9.32±1.93	0.100	9.81±1.54	9.87±1.71	0.100	0.270	0.25 (-0.3,0.3)	0.164
Subtotal	53.2±10.78	52.7±10.66	0.070	54.9±8.74	54.5±8.57	0.600	0.310	-0.25 (-0.3,0.3)	0.174
Total	57.2±10.90	56.8±10.71	0.080	56.4 (48.5-65.4)	55.5±9.25	0.060	0.290	0.24 (-0.5,0.3)	**0.044**

All the data are represented as mean ± SD for normal distribution data or median (interquartile range, IQR) for non-normal distribution data. The difference of the normal distribution data was tested by ANCOVA and that of the nonnormal distribution data was tested by the Man-Whitney U Test. P-value[a], duration effects (within CG), P-value[b], duration effects (within KKG), P-value[c], between Groups at baseline, P-value[d], between Groups after intervention. **CG** = Control Group,

KKG = Khon Kaen Qigong Group, **Pre** = Pre-assessment, **Post** = Post-assessment, **MD** = Mean difference, **%** = Percentage, **L** = Left, **R** = Right.

Table 2. Blood Biomarkers at Pre- and Post-Assessment in Both Groups.

Variable	**CG** (n = 23)		P-value[a]	**KKG** (n = 22)		P-value[b]	P-value[c]	MD [95% CI]	P-value[d]
	Pre	Post		Pre	Post				
FPG (mg/dL)	112 (85.5-150.2)	90 (82.8-129.2)	0.052	112±30.8	89 (82-143.5)	0.063	0.275	-1.5 (-5,3)	0.171
Insulin (uU/mL)	7 (5.27-9.05)	7 (4.82-10.9)	0.315	6 (3.63-10.3)	6.7 (5.11-10.6)	0.421	0.342	0.3 (-2,2)	0.545
HOMA-IR	2.2 (1.16-2.98)	1.9 (1.07-2.78)	0.083	1.4 (0.87-4.03)	1.4 (1.17-3.0)	0.208	0.408	-0.4 (-1,1)	0.866
TC (mg/dL)	211±34.6	200±44.6	0.061	230±36.6	226±38.4	0.072	0.245	-6.5 (10.5)	**0.048**
TG (mg/dL)	138±59.7	135±57.1	0.103	116 (95-148)	107 (75-140)	**0.041**	0.278	-4.2 (-12,6)	**0.049**
HDL-c (mg/dL)	51 (37-57)	51±11.3	0.204	53±15.4	53(42-67)	0.307	0.305	0.3 (-3,2)	0.142
LDL-c (mg/dL)	137±37.6	130±40.6	0.074	153±31.2	142.8±42.9	0.083	0.324	-4.5 (-10,8)	0.858
HDL-c/LDL-c	0.33 (0.26-0.48)	0.42±0.13191	**0.042**	0.36±0.11	0.38 (0.31-0.47)	0.051	0.308	0.04 (-0.1,0.1)	0.286
TC/HDL-c	4.45±1.29	4.08±1.09	0.053	4.14 (3.73-5.37)	4.18±1.47	0.105	0.355	-0.25 (-0.5,0.4)	0.839

All the data are represented as mean ± SD for normal distribution data or median (interquartile range, IQR) for non-normal distribution data. The difference of the normal distribution data was tested by ANCOVA and that of the nonnormal distribution data was tested by Man-Whitney U Test. P-value[a], duration effects (within CG), P-value[b], duration effects (within KKG), P-value[c], between Groups at baseline, P-value[d], between Groups after intervention. **CG** = Control Group, **KKG** = Khon Kaen Qigong Group, **Pre** = Pre-assessment, **Post** = Post-assessment, **MD** = Mean difference, **FPG** = fasting plasma glucose, **HOMA-IR** = Homeostatic Model Assessment for Insulin Resistance, **TC** = Total cholesterol, **TG** = Triacylglycerol, **HDL-c** = High-density lipoprotein cholesterol, **LDL-c** = Low-density lipoprotein cholesterol.

Table 3. The Correlation between MoCA Scores and Body Composition Variables Measured by Dual-Energy X-Ray Absorptiometry at Pre- and Post-Assessment in Both Groups.

Composition	Compartment	Pre				Post			
		CG (n = 23)		**KKG** (n = 22)		CG (n = 23)		**KKG** (n = 22)	
		r	P-value	r	P-value	r	P-value	r	P-value
Fat (%)	Head	0.07	0.70	0.05	0.78	0.09	0.62	0.18	0.41
	L Arm	0.18	0.41	0.15	0.54	0.20	0.36	0.35	0.13
	R Arm	0.16	0.46	0.13	0.57	0.18	0.39	0.32	0.16
	Trunk	0.25	0.24	0.28	0.21	0.27	0.23	0.40	0.11
	L Leg	0.22	0.30	0.24	0.29	0.25	0.25	0.38	0.12
	R Leg	0.20	0.33	0.22	0.31	0.23	0.27	0.36	0.14
	Subtotal	0.27	0.23	0.30	0.19	0.29	0.18	0.42	0.09
	Total	0.30	0.19	0.32	0.17	0.31	0.18	0.45	0.07
Subcutaneous Fat Mass (kg)	Arms	0.15	0.45	0.13	0.52	0.17	0.42	0.32	0.16
	Legs	0.22	0.32	0.24	0.30	0.24	0.28	0.37	0.13
	Trunk	0.25	0.26	0.28	0.22	0.28	0.20	0.42	0.09

Composition	Compartment	Pre				Post			
		CG (n = 23)		**KKG** (n = 22)		CG (n = 23)		**KKG** (n = 22)	
		r	P-value	r	P-value	r	P-value	r	P-value
	Whole body	0.20	0.35	0.18	0.39	0.22	0.32	0.38	0.12
Fat Mass (kg)	Head	0.06	0.79	0.04	0.84	0.08	0.69	0.19	0.39
	L Arm	0.15	0.52	0.12	0.59	0.17	0.48	0.31	0.17
	R Arm	0.13	0.57	0.10	0.63	0.15	0.52	0.29	0.19
	Trunk	0.26	0.22	0.29	0.20	0.28	0.19	0.41	0.10
	L Leg	0.23	0.29	0.25	0.27	0.26	0.22	0.39	0.11
	R Leg	0.21	0.32	0.23	0.30	0.24	0.26	0.37	0.13
	Subtotal	0.28	0.21	0.31	0.18	0.30	0.17	0.43	0.08
	Total	0.31	0.18	0.33	0.16	0.32	0.16	0.46	0.06
Lean Mass (kg)	Head	0.05	0.83	0.03	0.87	0.04	0.89	0.20	0.30
	L Arm	0.14	0.53	0.12	0.58	0.16	0.49	0.30	0.18
	R Arm	0.12	0.59	0.11	0.61	0.14	0.54	0.28	0.21
	Trunk	0.27	0.22	0.30	0.19	0.29	0.18	0.42	0.09
	L Leg	0.24	0.28	0.26	0.24	0.27	0.23	0.40	0.11
	R Leg	0.22	0.31	0.24	0.29	0.25	0.25	0.38	0.12
	Subtotal	0.29	0.19	0.32	0.17	0.31	0.18	0.45	0.07
	Total	0.33	0.16	0.36	0.13	0.34	0.15	0.49	0.05
Total Mass (kg)	Head	0.07	0.71	0.05	0.77	0.09	0.68	0.20	0.31
	L Arm	0.16	0.47	0.13	0.56	0.18	0.40	0.32	0.16
	R Arm	0.14	0.52	0.11	0.60	0.16	0.48	0.29	0.19
	Trunk	0.27	0.21	0.30	0.19	0.28	0.20	0.41	0.10
	L Leg	0.25	0.23	0.27	0.22	0.26	0.24	0.39	0.11
	R Leg	0.23	0.30	0.25	0.28	0.24	0.27	0.37	0.13
	Subtotal	0.30	0.19	0.33	0.16	0.31	0.18	0.44	0.07
	Total	0.36	0.14	0.39	0.11	0.35	0.15	0.51	0.06

Pearson correlation analysis (normally distributed data) and Spearman correlation analysis (non-normally distributed data) were used to analyze correlation among indicators. **MoCA** = Montreal Cognitive Assessment, **CG** = Control Group, **KKG** = Khon Kaen Qigong Group, **%** = Percentage, **L** = Left, **R** = Right.

Table 4. The Correlation between MoCA Scores and Blood Biomarkers at Pre- and Post-Assessment in Both Groups.

	Pre				Post			
	CG (n = 23)		**KKG** (n = 22)		**CG** (n = 23)		**KKG** (n = 22)	
	r	P-value	r	P-value	r	P- value	r	P-value
FPG (mg/dL)	0.15	0.45	0.12	0.58	0.18	0.38	0.32	0.15
Insulin (uU/mL)	-0.10	0.62	0.08	0.70	0.06	0.80	0.28	0.20
HOMA-IR	0.12	0.55	0.10	0.60	0.14	0.50	0.30	0.18
TC (mg/dL)	0.22	0.32	0.20	0.36	0.25	0.26	0.35	0.12
TG (mg/dL)	0.28	0.22	0.25	0.28	0.30	0.19	0.40	0.08
HDL-c (mg/dL)	0.35	0.12	0.38	0.10	0.38	0.10	0.45	0.05
LDL-c (mg/dL)	-0.12	0.52	-0.15	0.48	-0.10	0.60	-0.05	0.82

Pearson correlation analysis (normally distributed data) and Spearman correlation analysis (non-normally distributed data) were used to analyze correlation among indicators. Abbreviations: **MoCA** = Montreal Cognitive Assessment, **CG** = Control Group, **KKG** = Khon Kaen Qigong Group, **FPG** = Fasting Plasma Glucose, **HOMA-IR** = Hormone Model Assessment for Insulin Resistance, **TC** = Total Cholesterol, **TG** = Triacylglycerol, **HDL-c** = High-Density Lipoprotein Cholesterol; **LDL-c** = Low-Density Lipoprotein Cholesterol.

Additionally, the reduction in plasma TG concentration and subcutaneous adipose tissues of the lower limbs may reflect the increased TG lipolysis by lipases in subcutaneous adipose tissues yielding free fatty acid, which then mobilized along with the very low-density lipoprotein cholesterol (VLDL-c) in the blood (32). VLDL-c represent the main source of blood TG. Free fatty acids are then used by the active lower limb muscles. To provide energy, the uptake free fatty acids are oxidized in the mitochondria of the active muscles. This is confirmed by Earnest et al. (10) who reported that exercise enhanced the ability of skeletal muscles to use lipids as opposed to glycogen, thus decreasing the plasma lipid levels.

The reduction in plasma TG concentration according to low-intensity exercise, which is the similar level as that of KKQ (46) is supported by a review article published by Muscella et al. (31). This can be explained by many previous studies demonstrating that free fatty acid from TG is a major energy source for the muscles during exercise at this intensity (14,17,21,34,43). Together with the improved TG, the improved TC concentration supports the reduction in CVD risk because TC is an important factor in the development of atherosclerosis that is a pathological mechanism of the cardiovascular risk (25,30). This highlights the importance of KKQ training in decreasing coronary mortality.

Importantly, many articles have shown that Qigong improved total body mass and body fat mass, (7,18,40,44,47,49). However, no evidence on the effect of Muay Thai on these markers was reported. As mentioned above, Baduanjin and Wuqinxi improved all lipid profile, but this study found only improvements of some lipid profile. Many factors such as exercise intensity, sex, and metabolic status may be responsible for the absent beneficial effect. Regarding exercise intensity, a high amount of energy expenditure (1,100 kcal) which is greater than that provided by low-intensity exercise is needed to increase HDL-c (11). Furthermore, phenotypic sex differences in energy homeostasis and metabolic disease due to sex-specific biological systems in adults have been demonstrated (27). For example, Mann et al. (1) demonstrated that HDL-c improvements were found only in men. Accordingly, female participants in this study, which is the majority of the participants (only 1 man in each group) did not show significant results on HDL-c.

The present study did not find any change from the training in muscle mass of any specific body compartments. This may be due to many possible explanations. Firstly, the nature of exercise type and intensity may have influenced the lack of significant results. KKQ is a very low-intensity endurance exercise that stimulates less muscle synthesis than strengthening exercises (2). This is consistent with a previous study that did not find any change in muscle mass after aerobic exercise even at higher intensity (50% to 70%VO_{2peak}) (35). However, progressive aerobic exercise at higher intensity (60 to 80% heart rate recovery), shorter duration (20 to 45 min), similar frequency (3 or 4 sessions/week), and training duration (12 weeks) showed increases in whole muscle and single myofiber size and function in older women (13). Furthermore, progressive resistance training protocols based on an individual's target goals, physical capacity, and training status are recommended by American College of Sports Medicine position stand (3). Secondly, the lack of change may be explained by the endurance exercise-induced enhanced transition of fast-twitch to slow-twitch muscle fibers by remodeling histone methylation in the mitochondria (24). The transition is interesting and should be further explored in this exercise mode.

The lack of benefits of the training on blood glucose and insulin resistance contrasts with previous studies reporting the anti-hyperglycemic effects of Baduanjin and Wuqinxi in patients with T2D and Metabolic Syndrome (18,40). There are a few reasons for this discrepancy. Firstly, heterogeneity of gene expression pattern of the participants may be responsible. Some participants with T2D and non-diabetes are highly heterogeneous in their ability to improve insulin sensitivity according to endurance exercise training (15,42). Thus, such phenomenon (39) is possible to include a genetic component of different skeletal muscle gene expression patterns at baseline in our participants (7 in the CG and 2 in the KKG). Further investigation in the gene expression before and after KKQ training may disclose this phenomenon. Secondly, it may be due to the intensity and volume of exercise based on aerobic type (8). Endurance exercise training that has been shown to improve glycemia required higher intensity or volume. Kirwan et al. (20) showed that 9 months of vigorous endurance exercise training at approximately 80% of maximal heart rate improved glucose-stimulated insulin response and glucose disposal rate in 12 people aged 65 ± 1 year (mean ± SE) with normal glucose tolerance. Therefore, KKQ, which is very low-intensity aerobic exercise for 3 months may not have a sufficient impact to improve glycemia.

In addition, different methods used to assess insulin sensitivity may reveal different results. Kirwan et al. (9) assessed insulin sensitivity by a hyperglycemic clamp procedure that is more sensitive than the HOMA-IR used in this study. The former is a gold-standard method to assess pancreatic beta-cell sensitivity to glucose and measure insulin secretion in response to elevated blood glucose levels. Whereas, the latter method is commonly used because of its simplicity and requirement for which is calculated from circulating glucose and insulin concentrations after fasting (26). Lastly, baseline glycemic condition may contribute to the different results. Participants in many previous studies found the improved glycemic control had hyperglycemia (18,40). Most of our participants were non-diabetes who had normal range of blood glucose concentration. Naturally, the change of glycemic parameters could not change much regarding the intervention in the non-diabetes group. Thus, changes can be easily found in patients of those studies than in the present study.

Unexpectedly, we did not find a correlation between cognition and the metabolic biomarkers. However, reviews of the literature indicate that the link between the subjects' body composition compartments and cognition in patients with MCI is still unclear. Loss of muscle mass in the lower limbs has been shown to be associated with a higher MCI risk in old Japanese participants (4). In contrast, the other did not find the association in the elderly population with MCI (mean age 76 years) (38). The explanation may be due to the different methods used to measure body composition. The former used a bioelectrical impedance analyzer while the latter used computed tomography (CT). The bioelectrical impedance analyzer was reported to underestimate in measuring fat compartment (23) but overestimate in measuring skeletal muscle mass (50). CT is a gold standard measuring body composition, thus both studies may not be comparable.

The Strength of this Study

The strength of this study is the nature of training, which is a group exercise in participants' community. This is reflected by high adherence of practice, which is more than 90%. During the practice, leaders and friends promoted a friendly, supportive, and motivating training environment. Furthermore, the group of leaders corrected movements of the participants during all sessions of the exercise. Besides, the present study used a gold standard of measuring body composition, which is DEXA (28). Furthermore, all machines for measurements were calibrated before all analysis and blood samples were duplicated in every measurement. Based on the high adherence, and lack of injury, KKQ was considered practical and safe in terms of clinical application.

Limitations in this Study

There are several limitations in this study. The intensity and volume of the KKQ training in this study may not have been sufficient to significantly show the beneficial effect of the training on other metabolic biomarkers that are non-significant. Additionally, this study did not fully control external factors such as diet and medication, which may have influenced the metabolic biomarkers. However, the subjects were asked to maintain both factors and provide the detail of the diet record that shows the similar content of daily diet component and energy intake in our previous publication (45). In addition, the participants could maintain their medications throughout the experiment (45). Therefore, both factors should not potentially affect our results interpretation. The small sample size may have decreased the significance of the correlation between cognition and metabolic biomarkers which is the subsequent hypothesis. Sample size was calculated from the primary aim of this study. Lastly, the sex bias (4) may have contributed to the absent of significance in certain parameters, given that most participants were women. Thus, the results of this study may not apply to the male counterpart.

A further study investigating kinetics and cellular pathways of lipid in circulation according to KKQ is interesting and worth performing. Further assessing the gene expression before and after the KKQ training may disclose the effect of heterogeneity of genetic expression. In addition, research on modifying the type and intensity of KKQ training may reveal its significant impact. In detail, adding eccentric contraction to some postures by holding arms or legs against gravity slowly for longer time or adding external weight to either upper or lower limbs by carrying dumbbell or sandbag may be worth searching for the significant results. Regarding a sex bias in this study, there was only 1 man in each group. This study should be repeated with male older adults or comparing equal numbers of male and female participants. In addition, increasing sample size may disclose the significance of the correlation between cognition and metabolic biomarkers

CONCLUSIONS

The findings reveal that 12 weeks of KKQ training, a novel combination of Asian mode of exercise, improved lipid metabolism both in the blood and subcutaneous fat compartments and total fat mass in older adults with MCI. Furthermore, it reduced total body mass. However, these improvements were not related to cognition that was found to be improved by the training in our previous publication (45). Based on the findings, high adherence, and lack of injury, KKQ training has the potential to be recommended for a reduction of CVD risk factors for patients with impaired cognitive function.

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The Acute Effects of Attentional Focus on Side-Step Cutting Maneuver Performance and Knee Injury Risk in Female Rugby Football Players

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ABSTRACT

Prijosoesilo EA, Benjapalakorn B. This study examined the acute effects of attention focus on side-step cutting maneuver performance and risks of knee injury. Ten female rugby football players volunteered and were randomly assigned to perform side-step cutting using both the dominant leg and the non-dominant leg in 3 different attentional focus conditions: (I) internal focus; (E) external focus; and (C) control with a one-week washout period between the conditions. Side-step cutting performances were measured as distances and side-step cutting velocity, while movement quality and knee injury risk were assessed using the CMAS (the cutting movement assessment score). The results showed no significant differences in distance and velocity among all attentional focus conditions when side-step cutting was performed by the subjects' dominant leg. In contrast, only greater cutting velocity was found when the skill was performed with non-dominant leg under internal and external focus conditions, although only velocity differed significantly among the conditions (P = 0.01), external focus condition (2.39 ± 0.69) exhibited the lowest velocity, while the internal focus (2.52 ± 0.70) and the control (2.49 ± 0.62) conditions showed similar results For injury risk assessment, side-step cutting with external focus yielded the lowest CMAS scores for both the dominant (P = 0.16) and the non-dominant (P = 0.32) legs compared to the internal focus and control conditions, indicating better movement quality and reduced knee injury risk. In conclusion, external focus instructions enhanced movement safety without compromising performance. The difference in side-step cutting velocity among attentional focus conditions, particularly the lower velocity under external focus instruction, may be attributed to greater attentional resources being allocated to environmental cues and movement outcomes rather than body mechanics. This shift allows for more automatic and efficient motor control, which prioritizes movement quality over maximal speed, especially when using the non-dominant leg. These findings suggested that adopting an external focus of attention might assist in movement safety during the side-step cutting maneuver without sacrificing performance efficiency.

Key words: Attentional Focus, Knee Injury Risk, Movement Quality, Side-Step Cutting

INTRODUCTION

Side-step cutting is a crucial movement skill in most team sports such as rugby football, handball, football, netball, and basketball (14,16,20,33). It is also one of the most significant factors leading to non-contact anterior cruciate ligament injury (19,21). It was suggested 70% of anterior cruciate ligament (ACL) injuries in athletes were non-contact injury caused primarily from high-speed movements, such as the side-step cutting maneuver (5,19,22,30). Side-step cutting could create high multiplanar knee joint loading that exceeds tolerance of the ACL causing injuries on such part (1,12,27,32).

Studies have found that female athletes have a greater rate of ACL injury than male athletes by 2 to 8 times due to their physical characteristics, such as greater degree of knee valgus and higher ground reaction force (17,24). Koga et al. (21) found that knee abduction force can cause internal tibial rotation, higher knee joint loading during improper biomechanical side-step cutting maneuver. Although side-step cutting maneuvers have been found to be associated with ACL injuries in athletes, they remain an essential component of many team sports. Consequently, athletes must continually practice side-step cutting maneuver for competitive performance. Therefore, proper training techniques along with effective methods for preventing ACL injuries, are of utmost importance.

Several methods, such as neuromuscular training (18,31), whole body technique modification (11), soft landing (9), and attentional focus (10) were suggested to reduce the risk of an ACL injury from side-step cutting. Among these methods, instructed attentional focus, process which the athletes allocates mental resources to cues, stimuli, or states using selective attention, was found highly effective (28). Wulf (35,36) suggested that an internal focus of attention might encourage individuals to consciously control their movements, which may interfere with the body's automatic motor control processes. In contrast, external focus of attention would promote more automatic motor control, as movement execution is not disrupted by conscious attempt (36). Several studies found that attentional focus could lead to alterations in movement control patterns that help to reduce the risk of injury (3,4,6,39). Understanding the role of attentional focus in modulating movement control may provide practical insight for improving performance while minimizing injury risk. Therefore, the purpose of this study is to investigate the effects of attentional focus on side-step cutting performance and knee injury risks. Findings from this research could contribute to developing effective training strategies to enhance athletic performance and promote safer movement patterns in team sports.

METHODS

Subjects

Ten female rugby football players (age: 21.80 ± 2.70) with at least 1 year of training or competing experience participated in this study. All the subjects had body mass index (BMI) less than 25 kg·m^2, scored between 4 and 6 from the cutting measurement assessment, and processed Hamstring to Quadriceps (H-Q) ratio ≥ 0.6, and had no medical records of ACL injuries.

Procedures

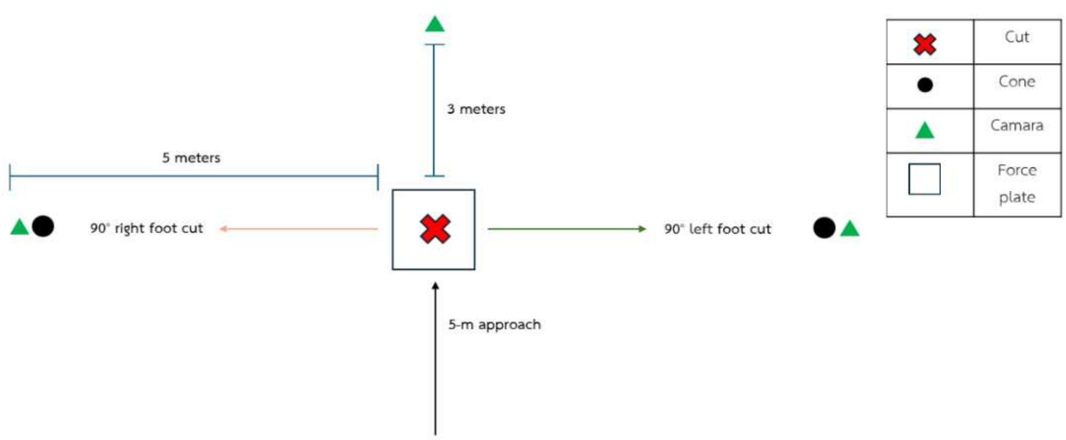
Hamstring Quadriceps Ratio Test

H:Q ratio was evaluated by using isokinetic dynamometer (Physiomed; CON-TREX multiple joint system Pro 3; Germany) with a concentric contraction test (CON/CON) at the angular velocity of 60° and 85° hip flexion. All the subjects were instructed to perform 5 repetitions of knee flexion and knee extension while seated on isokinetic dynamometer for 2 sets at 80% maximum strength in the 1st set and maximum effort for the 2nd set with a 2-minute rest between the set intervals. All the subjects performed the test starting with their dominant leg followed by their non-dominant leg, respectively.

The Cutting Measurement Assessment Scores (CMAS)

The CMAS qualitative screening was done by using a three-dimensional Motion analysis system (Qualisys; Miqus hybrid; Sweden) to record video data. Figure 1 shows the CMAS laboratory setup.

Figure 1. CMAS laboratory setup



The subjects were instructed to perform three 90-degree side-step cutting with a 2-minute resting interval between repetitions starting with the dominant leg to the non-dominant leg. Once the cutting footage was collected, the cutting footage was viewed frame-by-frame and the scoring was based on the 9-item CMAS qualitative screening tool.

Markers' Placement

Forty-five reflective markers were placed on the following body landmarks: center of forehead, above left and right ears, acromion processes, sternum, T2, T12, medial humeral epicondyles, lateral humeral epicondyles, ulnar styloid process, radial styloid process, 2nd metacarpal, anterior superior iliac spines, greater trochanter, sacrum, medial femoral epicondyles, lateral femoral epicondyles, medial tibial epicondyles, lateral tibial epicondyles, patella, tibial tubercle, lateral malleoli, 1st metatarsal, 5th metatarsal, calcaneus distal, and calcaneus proximal. Figure 2 shows markers placement.

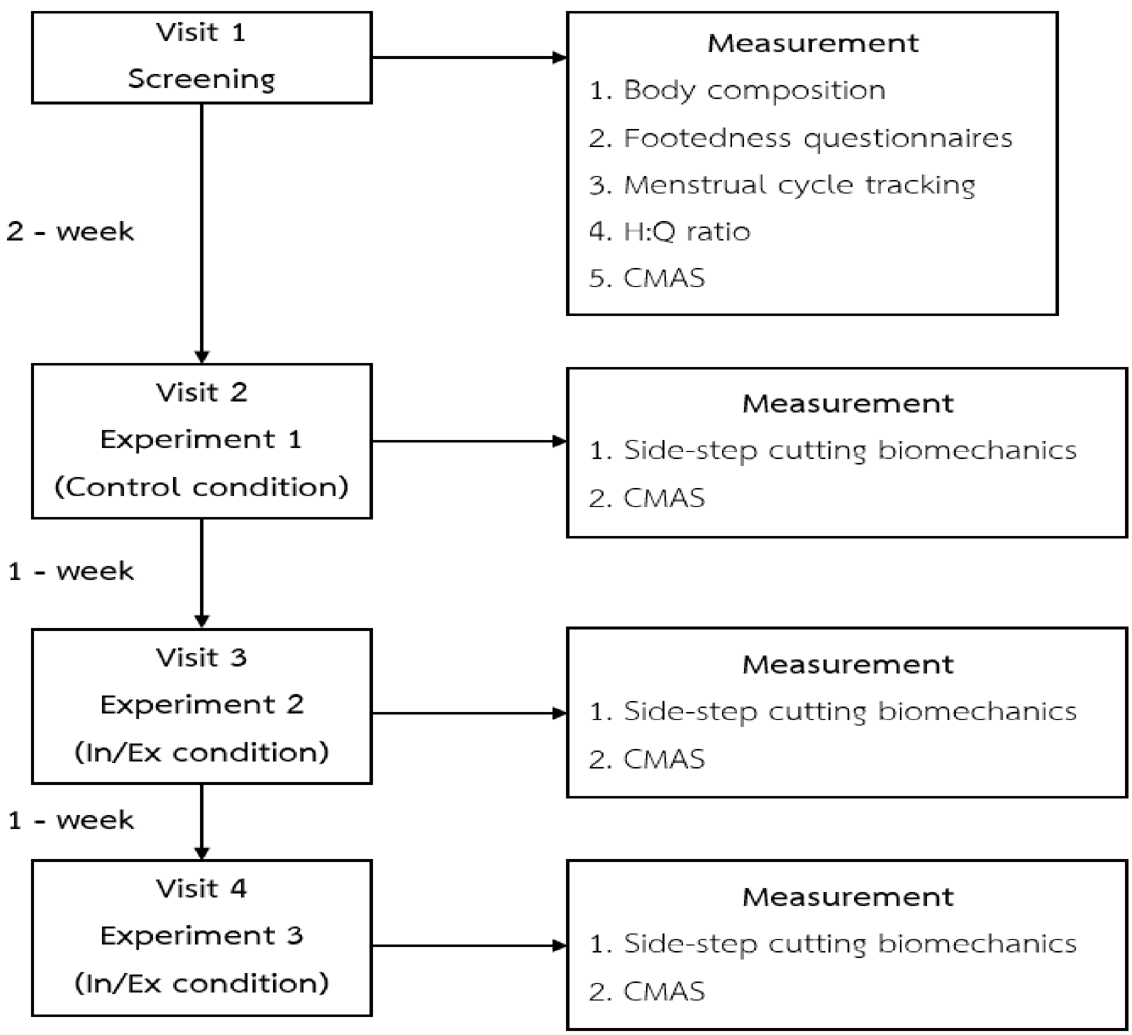
Figure 2. Markers' Placement.

Experimental Protocols

The study was conducted at the Biomechanics Laboratory, Faculty of Sports Sciences, Chulalongkorn University, Bangkok, Thailand. The study protocol was approved by the research ethics review committee for research involving humans at Chulalongkorn University.

Design of the present study is shown as in Figure 3. Each participant was required to visit the testing site 4 times. Body composition, footedness questionnaires, menstrual cycle tracking, H:Q ratio, and the CMAS were all tested in the 1st visit, while cutting mechanics and CMAS scores were collected during the 2nd, 3rd, and 4th visits with different attention focus conditions.

Figure 3. Study Design.



Upon arrival at the testing site, the participants were instructed to perform a standardized warm-up, followed by 5 side-step cutting trials using both the dominant leg and the non-dominant leg for familiarization. The participants then received verbal explanations of the attentional focus instructions that were shown in Table 1, and they completed 3 practice side-step cutting trials under these conditions. Reflective markers were placed on the participants according to the prescribed marker set. The formal testing session began with 3 side-step cutting trials using the dominant leg, followed by 3 trials using the non-dominant leg. A 2-minute rest interval was provided between each trail.

Table 1. Attentional Focus Verbal Instructions.

Conditions	Verbal Instructions
Control	"Change the direction on the force plate as fast and as far as possible."
Internal Focus	"Change the direction on the force plate, while focusing on keeping the toes pointed in the same direction as the knee, performing the movement as fast and as far as possible."
External Focus	"Change the direction on the force plate, while focusing on the side cone, performing the movements as fast and as far as possible."

Statistical Analysis

All the data were analyzed using SPSS version 29.0.2 for Windows (SPSS Inc., USA). The Shapiro-Wilk Test was used to assess data normality. The one-way repeated measures test (ANOVA) was used to compare side-step cutting distance, side-step cutting speed, and the CMASs across 3 different conditions. Paired *t*-tests were used to compare results between dominant and non-dominant legs. Statistically significant differences were identified at a significant level of $P < 0.05$.

RESULTS

Table 2. Physiological Data of 10 Female Rugby Football Players.

Physiological Data	Mean ± SD
Age (years)	21.80 ± 2.70
Height (meters)	1.60 ± 0.03
Weight (kilograms)	57.97 ± 9.51
BMI (kg/m^2)	22.73 ± 3.13
H:Q Ratio	
- **Dominant Legs**	0.657 ± 0.097
- **Non-Dominant Legs**	0.682 ± 0.113
Lower Extremity (meters)	
- **Dominant Legs**	0.80 ± 0.04
- **Non-Dominant Legs**	0.80 ± 0.03

Side-step cutting distance and velocity, as well as CMAS scores of subjects' dominant legs are shown in Table 3. It was found that side-step cutting distance was greatest in control condition (129.80 ± 20.40) compare with the internal (128.68 ± 15.23) and external focus (128.07 ± 15.25) conditions; however, the difference was not statistically significant (P = 0.74). Similarly, the control condition showed slightly higher cutting velocity (2.57 ± 0.58) than the internal focus (2.53 ± 0.66) and external focus (2.50 ± 0.60) conditions, with no significant difference observed (P = 0.60) Conversely, both internal and external focus conditions resulted in lower CMAS scores (3.90 ± 1.36 and 3.86 ±

1.28, respectively) compared with the control conditions (4.40 ± 1.63), though this difference was not statistically significant (P = 0.16).

Table 3. Side-Step Cutting Performance and CMASs with Dominants Legs.

	Internal Focus	External Focus	Control	ANOVA	
				F	P-Value
SSC Distance (%)	128.68 ± 15.23	128.07 ± 15.25	129.80 ± 20.40	0.17	0.74
SSC Velocity ($m \cdot s^{-1}$)	2.53 ± 0.66	2.50 ± 0.60	2.57 ± 0.58	0.39	0.60
The CMASs (score)	3.90 ± 1.36	3.86 ± 1.28	4.40 ± 1.63	2.02	0.16

The data are presented as mean ± SD. **SSC Distance** = Side-Step Cutting Distance (cutting distance/lower extremity length), **SSC Velocity** = Side-Step Cutting Velocity, **CMAS** = The Cutting Movement Assessment Score.

Side-step cutting distance and velocity, as well as CMAS scores of subjects' non-dominant legs are presented in Table 4. Side-step cutting distance showed no significant difference among 3 attentional focus conditions, although both internal focus (126.04 ± 13.99) and external focus (126.72 ± 16.50) conditions demonstrated slightly greater distances than the control group (123.05 ± 13.40) (P = 0.47). For side-step cutting velocity, a significant difference was observed among conditions (P = 0.01). The external focus condition (2.39 ± 0.69) exhibited the lowest velocity, while the internal focus (2.52 ± 0.70) and control (2.49 ± 0.62) conditions showed similar results. For CMAS scores, no significant difference was found among conditions (P = 0.32). However, the external focus condition (3.46 ± 1.07) demonstrated lower CMAS scores than the internal focus (3.83 ± 1.42) and control (3.97 ± 0.99) conditions.

Table 4. Side-Step Cutting Performance and the CMASs with Non-Dominant Legs.

	Internal Focus	External Focus	Control	ANOVA	
				F	P-Value
SSC Distance (%)	126.04 ± 13.99	126.72 ± 16.50	123.05 ± 13.40	0.79	0.47
SSC Velocity ($m \cdot s^{-1}$)	2.52 ± 0.70[b]	2.39 ± 0.69[a, c]	2.49 ± 0.62[b]	6.78	0.01
The CMASs (score)	3.83 ± 1.42[b]	3.46 ± 1.07[a]	3.97 ± 0.99	1.13	0.32

The data are presented as mean ± SD. [a]P < .05 vs. internal focus group, [b]P < .05 vs. external focus group, [c]P < .05 vs. control group.

The comparison of side-step cutting performance and CMAS scores between the dominant and non-dominant legs across all attentional focus conditions is presented in table 5. Under the internal focus conditions, side-step cutting distance (P = 0.63), velocity (P = 0.76), and CMAS scores (P = 0.83) did not differ significantly between legs, Similarly, in the external focus condition, no significant differences were observed in side-step cutting distance (P = 0.78), velocity (P = 0.27), or CMAS scores (P = 0.30). Under the control condition, the dominant leg showed slightly greater side-step cutting distance than the non-dominant leg, but the difference was not significant (P = 0.12). Side-step cutting velocity (P = 0.21) and CMAS scores (P = 0.42) also showed no significant difference.

Table 5. The Comparison Between Dominant and Non-Dominant Legs.

	Internal Focus		P-Value	External Focus		P-Value	Control		P-Value
	DOM	NDOM		DOM	NDOM		DOM	NDOM	
SSC Distance (%)	128.68 ± 15.23	126.04 ± 13.99	0.63	128.07 ± 15.25	126.72 ± 16.50	0.78	129.79 ± 20.40	123.05 ± 13.99	0.12
SSC Velocity ($m \cdot s^{-1}$)	2.53 ± 0.66	2.52 ± 0.70	0.76	2.50 ± 0.60	2.39 ± 0.69	0.27	2.57 ± 0.58	2.49 ± 0.62	0.21
The CMASs (score)	3.90 ± 1.36	3.83 ± 1.42	0.83	3.86 ± 1.28	3.46 ± 1.07	0.3	4.40 ± 1.63	3.97 ± 0.99	0.42

DISCUSSION

The purpose of this study was to examine the influence of attentional focus instructions on side-step cutting performance and movement quality, as measured by CMAS, in both the dominant and non-dominant legs. The findings suggests that attentional focus instructions had minimal impact on side-step cutting performance outcomes. Instead, it played more a role in movement quality improvement, as reflected by the lower CMAS scores, particularly for the non-dominant leg.

For the dominant leg, side-step cutting distance and velocity did not differ significantly among internal focus, external focus, and control conditions. Although the control condition showed marginally higher distance and velocity, these differences were not statistically significant (P = 0.74 and P = 0.60, respectively). The results suggest that the athletes' dominant leg performance is robust and less sensitive to variations in attentional focus instructions. The dominant leg is typically more coordinated and stable during high-intensity movements, such as cutting due to greater neuromuscular familiarity and control developed through repeated use in sport-specific tasks. Therefore, attentional focus manipulations may have limited impact on performance outcomes when movement patterns are already well-established and efficient.

Some studies indicate that the effect of attentional focus was limited for athletes who were familiar with motor tasks that they spontaneously mobilized the automatic control system, even without any instruction (7,34,35,39). Conversely, both internal and external conditions resulted in slightly lower CMAS scores compared with the control condition, although the differences were not statistically significant ($P = 0.16$). This suggests a tendency towards improved movement quality when attentional focus instructions are provided, potentially reducing the risk of maladaptive movement patterns associated with higher knee loading or injury risk (6,10). These findings are consistent with previous studies that suggest attentional focus, particularly external focus, can enhance motor coordination and reduce excessive joint loading during cutting or landing maneuvers (8,25,36,38).

For the non-dominant leg, the results showed a significant difference in side-step cutting velocity among attentional focus conditions ($P = 0.01$), with the external focus (2.39 ± 0.69) condition demonstrating the lowest velocity compared to the internal (2.52 ± 0.70) and control (2.49 ± 0.62) conditions. Although both the internal and external focus conditions produced slightly greater side-step cutting distances than the control condition, the differences were not statistically significant ($P = 0.47$). These findings indicate that attentional focus may influence how athletes control their movement strategy during side-step cutting tasks when using the non-dominant leg.

The reduced velocity observed in the external focus condition may indicate a more cautious or controlled movement pattern that potentially contributes to safer mechanics (2,13). Although no significant differences were found for CMAS scores ($P = 0.32$), the external focus condition again produced the lowest mean score (3.46 ± 1.07), followed by internal focus (3.83 ± 1.42) and control conditions (3.97 ± 0.99). The absence of a statistically significant difference may contribute to the small sample size and individual variability in the participants' movement control that can reduce the power to detect subtle differences. Nevertheless, the consistent trend toward lower CMAS scores under external focus conditions suggest a potential practical benefit. This supports the notion that external focus instructions can promote more efficient and stable movement patterns, particularly in the less dominant limb, which aligns with the previous research indicating that external focus facilitates automatic motor execution, particularly in less skilled limbs (23,29,37).

When comparing dominant and non-dominant legs across all attentional focus conditions, no significant differences were observed in side-step cutting distance, velocity, or the CMAS scores. This suggests that both legs demonstrated comparable performance levels, which may be due to the participants' training background and balanced lower-limb use in their sport. However, slight trends indicated that the dominant leg tended to achieve slightly greater distance and velocity under the control condition; whereas, the non-dominant leg showed marginally better movement quality under attentional focus conditions. These trends suggest that attentional focus instructions may be more beneficial for improving the control and coordination of the non-dominant leg, which generally exhibits less automaticity in movement execution.

CONCLUSION

Attentional focus instructions did not significantly affect the side-step cutting maneuvers performance in either the dominant leg or the non-dominant leg. Although a significant difference in velocity among focus conditions was found for the non-dominant leg. Both internal and external focus conditions tended to produce lower CMAS scores that suggested improved movement quality. The results indicate that attentional focus, particularly external focus, may play a more significant role in refining movement control rather than directly enhancing performance outcomes, especially for the non-dominant leg. These findings suggest that we should consider implementing external focus cues to optimize side-step cutting performance safety and long-term injury prevention in athletic populations.

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4-Corner Elastic Jumping (Kradod Yang) Test: Culturally Grounded Assessment of Dynamic Motor Competence in Youth

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ABSTRACT

Tongterm T, Kaewma J, Chansrisukot G, Boonprom T. 4-Corner Elastic Jumping (Kradod Yang) Test: Culturally Grounded Assessment of Dynamic Motor Competence in Youth. The purpose of this study was to develop and validate the 4-Corner Elastic Jumping (Kradod Yang) Test, a culturally grounded field-based assessment of dynamic motor competence adapted from the Thai traditional game. A sequential multiphase Psychometric Research and Development (R&D) design was used. Content validity was confirmed by 5 sports-science experts (Index of Item-Objective Congruence = 0.89). Forty healthy youths aged 18–24 years completed the developed test and 4 standardized balance tests to determine reliability and discriminant validity. The test showed good reliability (intra-rater ICC = 0.81; inter-rater ICC = 0.77). Correlation coefficients with standard balance tests were low (r = –0.31 to 0.21), indicating that the test measures a distinct construct of dynamic balance and coordination. Feasibility and user satisfaction were assessed with a 5-point Likert scale among 30 the administrators and 40 participants. The participant satisfaction was very high (M = 4.56, SD = 0.56), and administrator satisfaction was high (M = 3.86, SD = 0.99). Preliminary percentile-based reference data from 900 healthy youths demonstrated strong field applicability. The findings confirmed that the 4-Corner Elastic Jumping (Kradod Yang) Test is reliable, feasible, and culturally authentic, It represents a sustainable model for Culturally Adaptive Assessment Tools that integrate traditional recreation with evidence-based motor-competence evaluation.

Key Words: Cultural Assessment, Discriminant Validity, Dynamic Motor Competence, Thai Traditional Game

INTRODUCTION

The assessment of motor competence has evolved substantially over the past 2 decades, marking a paradigm shift in sports science and physical education toward dynamic, ecological, and culturally responsive approaches. Early frameworks emphasized isolated motor skills such as static balance, agility, and muscular strength, and yet current models view movement as a multidimensional construct encompassing perceptual–motor coordination, adaptability, and environmental interaction. The Dynamic Model of Motor Competence provides the theoretical foundation for understanding how the ability to perform coordinated and adaptable movements influences lifelong engagement in physical activity and overall health (3,4). Consequently, developing field-based tools that authentically represent integrated motor processes has become a global research priority within the discipline of motor development and health-related physical education (19).

Empirical studies have consistently demonstrated that traditional and folk games serve as effective and culturally grounded contexts for developing motor competence in children and youth (1,2). Such games require repetitive and diverse movement patterns that enhance neuromuscular coordination, proprioceptive control, and balance adaptation through socially interactive play. Their ecological validity stems from the natural integration of rhythm, cooperation, and cultural familiarity that sustains intrinsic motivation among the participants (24). Accordingly, traditional games not only foster fundamental locomotor and manipulative skills but also provide reliable frameworks for culturally adaptive motor assessments, bridging recreational practices with empirical measurement of motor behavior (12,22).

Beyond the physical domain, folk games play a central role in psychosocial well-being and cultural sustainability. Cooperative and community-based play fosters empathy, emotional intelligence, and social inclusion while reducing stress and strengthening a sense of belonging (17). From a cultural perspective, such activities function as living expressions of heritage, transmitting collective values and identity across generations. Their integration into educational and scientific frameworks supports the global movement toward culturally responsive pedagogy and inclusive physical education (6,10). This alignment of indigenous wisdom with scientific assessment highlights the potential of traditional games to contribute both to psychosocial development and to the advancement of evidence-based evaluation tools.

Despite these advances, a significant gap remains in the availability of validated Culturally Adaptive Assessment Tools (CAATs) capable of measuring Dynamic Motor Competence (DMC) in ecologically valid field environments. Conventional balance assessments such as the Star Excursion Balance Test and the Y Balance Test, although psychometrically sound, often lack cultural resonance and engagement among youth populations (26). In Thailand, the traditional game Kradod Yang (elastic jumping) incorporates rhythmic, sequential, and multidirectional lower-limb movements under elastic tension, demanding continuous balance control and coordination that reflect higher-order DMC (29,30). Building upon this foundation, the present study introduces the 4-Corner Elastic Jumping (Kradod Yang) Test, a field-based assessment developed to evaluate dynamic balance and multidirectional control within a culturally familiar framework. Thus, the purpose of this study was to (a) develop the 4-Corner Elastic Jumping (Kradod Yang) Test as a culturally grounded dynamic motor competence assessment adapted from the Thai traditional game; (b) examine its psychometric properties, including intra- and inter-rater reliability and discriminant validity; (c) evaluate feasibility and user satisfaction in the practical youth settings; and (d) generate preliminary percentile-based reference data illustrating general applicability rather than normative standardization. Collectively, these objectives reflect a dual commitment to scientific rigor and cultural preservation, advancing an assessment model that bridges heritage and innovation in pursuit of holistic youth development.

METHODS

This study adopted a sequential, multiphase Psychometric Research and Development (R&D) design framed within a mixed-methods paradigm. The methodological framework was systematically structured to integrate psychometric precision that is essential for instrument validation, with pedagogical applicability to ensure that the developed test could be feasibly implemented in authentic educational and community contexts. Quantitative analyses were used to determine reliability, discriminant validity, and percentile-based reference data; whereas, qualitative inquiry captured insights regarding usability and user engagement. All research procedures complied with the ethical standards of the Research Ethics Review Committee of Sisaket Rajabhat University (Protocol No. HE671003). Informed consent was obtained from the participants prior to their involvement.

Participants and Stratified Sampling

Four progressively structured participant cohorts were recruited, corresponding to the stages of the R&D process.

1. Instrument Development and Refinement (Phase 1): A small-scale pilot testing was first conducted with 5 healthy youths (2 females, 3 males) and, subsequently, with a cohort of 30 participants (15 males, 15 females; aged 18 to 24 years) to ensure clarity of instructions, procedural safety, and appropriate movement scaling.

2. Psychometric Validation (Phase 2): A purposive sample of 40 healthy youths (20 males, 20 females; aged 18 to 24 years) was employed to evaluate the intra- and inter-rater reliability and to examine discriminant validity against standard balance assessments. Justification of Validation Sample Age: This age group was specifically selected to establish psychometric stability under conditions of mature and consistent motor skills, thereby minimizing developmental variability before future scaling to the younger populations (7).

3. Feasibility and Pedagogical Evaluation (Phase 3): Two subgroups participated: 30 sports-science students acted as test administrators, and 40 youths served as test participants to assess clarity, safety, and engagement.

4. Reference Data Generation (Phase 4): A large-scale cohort of 900 healthy youths (270 males, 630 females; aged 18 to 24 years) provided percentile-based data to demonstrate field applicability as a feasibility benchmark rather than fixed national norms (19).

All testing was conducted between May 2025 and September 2025 at the Sports Science Field Laboratory, Sisaket Rajabhat University, under controlled environmental conditions (temperature 27 to 30°C; non-slip surface).

Instrument Development: The 4-Corner Elastic Jumping (Kradod Yang) Test

The 4-Corner Elastic Jumping (Kradod Yang) Test was systematically adapted from the Thai traditional game Kradod Yang ("elastic jumping") to create a culturally grounded innovation in motor fitness assessment. Unlike conventional static balance tests, this design emphasizes Dynamic Motor Competence (DMC) characterized by continuous postural control, rhythm adaptation, and multidirectional coordination (17). The final protocol consists of 3 sequential rounds performed barefoot within a demarcated 3 m × 3 m square using braided elastic bands: 1) Straddling movement (orientation phase); 2) Two-foot jumping (bilateral stability); and 3) Single-leg hopping (unilateral control).

Total Completion Time (TCT) in seconds served as the principal performance indicator. Content validity was verified by a panel of 5 doctoral-level experts in sports science and physical education, achieving an Index of Item-Objective Congruence (IOC = 0.89) that confirmed a strong conceptual alignment between objectives and measurable indicators (23).

Scoring Protocol and Error Management

To ensure high replicability and technical rigor in scoring, a structured penalty system was employed. The Total Completion Time (TCT) was computed as:

$$TCT = Time_{(Observed)} + \Sigma \text{ (Penalty Time)}.$$

Minor errors and disqualifying errors were managed as follows.

Minor Movement Penalties:

- Touching the elastic band or pole (Round 1): 1-second time penalty per instance.
- Loss of foot contact with the elastic band (Rounds 2–3): 1-second time penalty per occurrence.

This scoring system enhanced data retention and ensured reproducibility while maintaining psychometric accuracy (15).

Disqualification Errors (Fail):

- A trial was immediately stopped and recorded as Did Not Complete (Fail) if the participant lost balance and touched the ground with the hands or switched the dominant foot during Round 3.

These trials were excluded from the subsequent analysis.

Reference Assessments for Discriminant Validity

To evaluate discriminant validity, the 4-Corner Elastic Jumping Test scores were correlated with 4 standardized assessments: (a) the Flamingo Balance Test – a static balance measure (14); (b) the Y Balance Test (YBT) – a dynamic balance and core stability measure (26); (c) the Star Excursion Balance Test (SEBT) – assesses multidirectional lower-limb stability (11); and (d) the Functional Reach Test (FRT) – measures forward dynamic stability (9).

These references represent the standard domains of balance assessment and provided comparative evidence of construct distinctiveness for DMC (21).

Reliability Assessment

Reliability analyses were conducted on the validation cohort (n = 40). Intra-rater reliability (test–retest within 7 days) employed the ICC(3,1) model, and inter-rater reliability (2 independent assessors, same day) employed the ICC(2,1) model (27). Interpretations followed Koo and Li (2016): ICC between 0.75 and 0.90 indicates good reliability. The 4-Corner Elastic Jumping Test achieved ICC = 0.81 (intra-rater) and ICC = 0.77 (inter-rater), confirmed strong reliability and stability across the observers and trials.

Feasibility and User Satisfaction

Feasibility and usability were assessed using a 5-point Likert-type questionnaire to evaluate clarity, safety, enjoyment, and challenge (31). Mean scores equal to or greater than 4.20 indicated Very High Satisfaction. The analysis yielded mean scores of 3.86 among the administrators and 4.56 among the participants, which reflected high to very high satisfaction levels and supporting the test's pedagogical applicability and engagement potential.

Reference Data Generation

Data from the large-scale cohort (N = 900) were used to compute percentile ranks (P_{10}, P_{25}, P_{50}, P_{75}, P_{90}) following the method of Miguel-Etayo et al. (20). Percentile values were stratified by sex to illustrate performance distribution across the youth population. These data demonstrate the test's field applicability and feasibility for broad motor assessment, not for normative standardization.

Data Analysis Protocol

All quantitative analyses were performed using IBM SPSS Statistics version 28. Intraclass Correlation Coefficients (ICC) with 95% confidence intervals were calculated for reliability evaluation. Pearson's correlation coefficient (r) was used to assess discriminant validity; low correlation values with standard balance tests were interpreted as evidence of distinct construct measurement rather than instrument weakness (13). Descriptive statistics including mean, standard deviation, minimum, and maximum values were computed for performance indices. Feasibility data were analyzed per Vonglao (31), and percentile ranks were calculated separately for males and females.

RESULTS

The empirical findings are presented systematically according to the study's 4 objectives, encompassing the test's development, reliability and validity, feasibility, and normative reference data. The inclusion of 10 procedural figures ensured comprehensive visualization of each testing stage, which is central to the transparency and ecological rigor of this field-based assessment.

1. Development and Content Validation

The 4-Corner Elastic Jumping (Kradod Yang) Test was developed as a culturally grounded field-based assessment adapted from the Thai traditional game Kradod Yang. The design integrated rhythmic, sequential, and multidirectional movements to assess dynamic motor competence (DMC) in authentic, culturally relevant contexts.

1.1 Conceptual Development

The development of the 4-Corner Kradod Yang Test originated from the Thai traditional game Kra Dot Yang, a cultural heritage activity widely played by Thai children aged 10 to 14 years using a hand-woven braided elastic band (Figure 1A) fixed to lightweight poles (Figure 1B). The traditional game involves rhythmic and patterned jumping sequences that foster essential motor abilities such as balance, coordination, and agility (Figure 2). Building on this cultural foundation, the research team systematically transformed the folk game into a standardized motor assessment that emphasized ecological validity, measurement reproducibility, and participant safety.

To ensure accurate measurement, a set of supportive field instruments was incorporated. The instruments included a measuring tape for calibration of square dimensions and jump distances, and a stopwatch for timing performance (Figure 3C–D). In addition, a red cloth tape was used to mark the starting rectangle and corner reference lines, while a whistle provided auditory start and stop cues (Figure 4E–F). Together, the instruments ensured procedural standardization and enhanced inter-rater consistency.

Five domain experts in sports science, motor learning, and recreation evaluated the test for conceptual clarity, construct alignment, and representativeness of the intended motor domains. Their evaluation yielded an Index of Item–Objective Congruence (IOC = 0.89), confirming excellent content validity. The finalized test station was constructed as a 3 × 3 m square, framed by braided elastic bands under uniform tension and marked with a red-taped starting area of 50 × 100 cm (Figure 5). This culturally grounded apparatus preserved the authenticity of Kra Dot Yang while achieving scientific precision suitable for dynamic motor competence assessment.

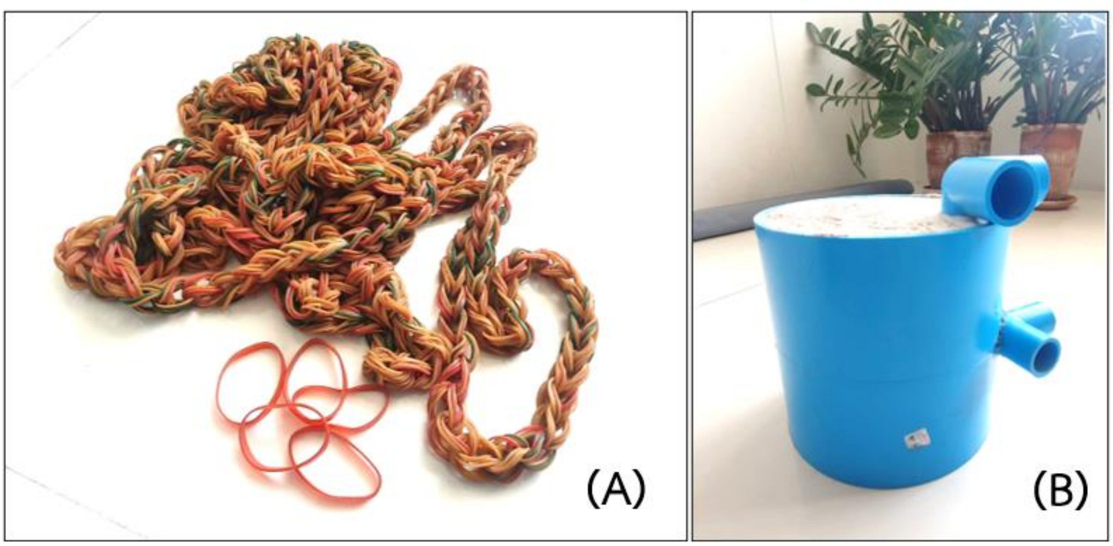

Figure 1. Braided Elastic Band (A) and Counterweight Pole (B).

Figure 2. “Kra Dot Yang” as a Traditional Thai Folk Game (Researcher’s Illustration).

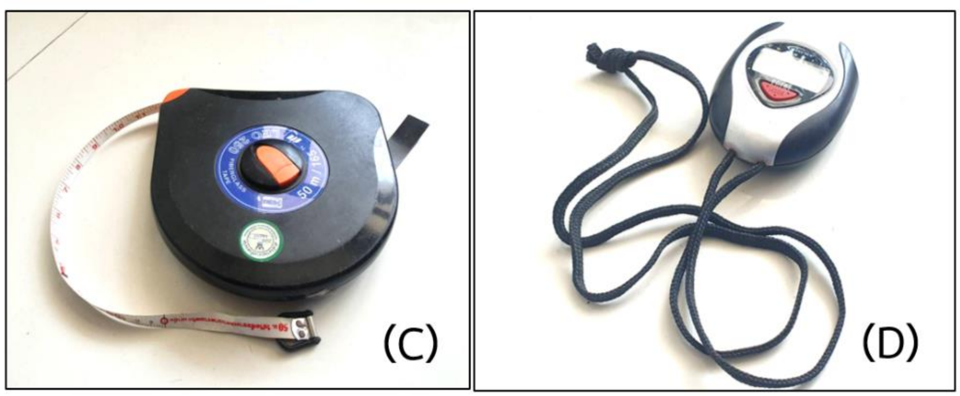

Figure 3. Measuring Tape (C) and Stopwatch (D).

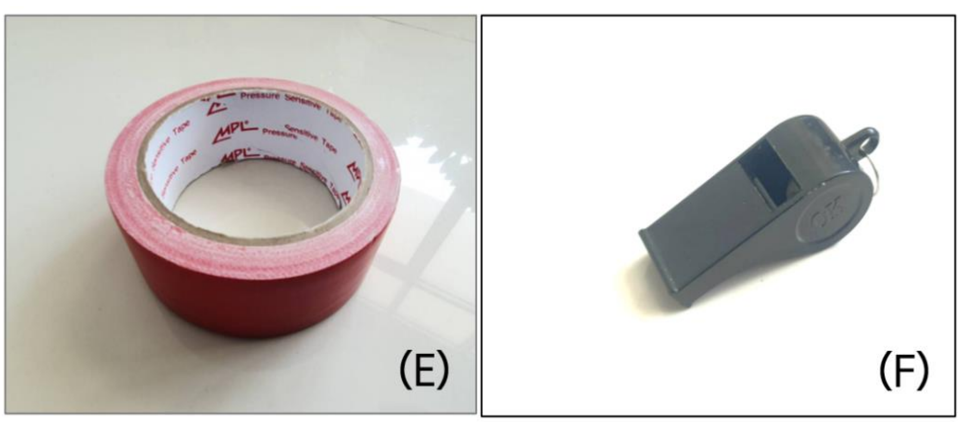

Figure 4. Red Cloth Tape (E) and Whistle (F).

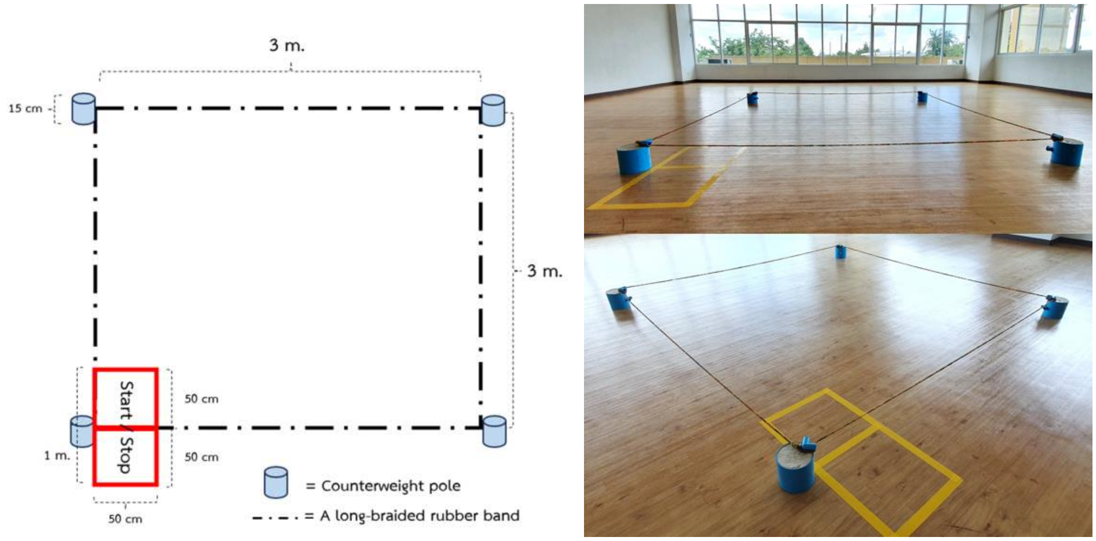

Figure 5. Setup of the Thai Kradod Yang Square Test Station.

1.2 Standardized Testing Procedure

To ensure replicability, procedural transparency, and inter-rater consistency, a standardized 3-round testing protocol was established and illustrated in Figures 6 through 10. Each participant completed 1 to 3 familiarization trials prior to formal testing. The testing area maintained a 2 m safety clearance zone around the 3 × 3 m elastic-square frame to prevent interference and ensure participant safety.

- Initial Setup (Figure 6): The participants removed their shoes and positioned themselves astride the braided elastic band at the red-taped starting rectangle. Upon receiving the verbal cue “Start,” the timer was activated. The measuring tape and stopwatch (see Figure 3.) were used to ensure consistent station dimensions and precise timing accuracy.

Figure 6. Initial Participant Setup and Safety Positioning.

- Round 1 – Straddling Movement (Figure 7): The participants moved rapidly along the 4 sides of the elastic square using straddling or running motions while maintaining an upright posture and avoiding contact with the elastic band or poles. This phase primarily assessed rhythmic coordination and dynamic stability during continuous lateral transitions.

Figure 7. Round 1: Straddling Movement Sequence Around the Elastic Square.

- Round 2 – Two-Footed Jumping (Figure 8): Without pause, the participants continued to perform synchronized 2-footed jumps along each side of the elastic boundary. The test administrator used the whistle cue (see Figure 4) to mark the start and the end of each round to ensure uniform timing signals. This stage emphasized bilateral coordination and postural control under rhythmic constraints.

Figure 8. Round 2: Two-Footed Jumping Pattern.

- Round 3 – Single-Leg Hopping (Figure 9): The participants performed continuous hops on their dominant foot along all 4 sides of the square, maintaining contact with the elastic band throughout. Touching the band with the hand or switching feet constituted a disqualification. This round targeted unilateral balance, muscular endurance, and neuromotor control.

Figure 9. Round 3: Single-Leg Hopping Pattern.

- Completion and Scoring (Figure 10): The trial concluded when the participant returned to the red start area by jumping over the elastic band. The stopwatch was stopped immediately upon completion, and the total time (seconds) served as the performance score. Observers recorded additional qualitative notes such as rhythm, control, and error frequency for interpretive validation.

Figure 10. Completion Phase and Performance Timing Procedure.

All procedures were conducted under uniform field conditions and safety protocols. This structured format ensured reproducible assessment of Dynamic Motor Competence (DMC) through multidirectional, rhythmically constrained, and culturally embedded movement patterns.

2. Reliability Analysis

Reliability evaluation was conducted among 80 healthy Thai youths 18 to 24 years of age, independently assessed by 2 trained raters under identical field conditions. The purpose of the analysis was to verify the internal consistency and inter-observer reproducibility of the 4-Corner Elastic Jumping (Kradod Yang) Test across repeated administrations.

As presented in Table 1, the test demonstrated good reliability according to Koo and Li's (2016) classification. Specifically, intra-rater reliability showed high internal consistency (ICC(3,1) = 0.81, 95% CI: 0.72–0.87), confirming that repeated scoring by the same rater produced stable outcomes. Likewise, inter-rater reliability indicated strong agreement between two independent raters (ICC(2,1) = 0.77, 95% CI: 0.62–0.86), ensuring reproducible evaluation standards across observers.

The combined evidence from both coefficients supports the test's psychometric robustness, indicating that scoring, timing, and performance classification were consistent across raters and test sessions. This reliability pattern validates the Kradod Yang Test as a dependable tool for assessing Dynamic Motor Competence (DMC) in authentic field settings.

Table 1. Intra- and Inter-Rater Reliability of the 4-Corner Elastic Jumping (Kradod Yang) Test.

Reliability Type	n	ICC (Model)	95% CI	Interpretation
Intra-rater	80	0.81 (3,1)	0.72–0.87	Good
Inter-rater	80	0.77 (2,1)	0.62–0.86	Good

The results in Table 1 confirmed that the 4-Corner Elastic Jumping (Kradod Yang) Test achieved consistent, replicable, and field-reliable measurements, thereby supporting its empirical credibility for educational and community-based motor assessment.

3. Criterion-Related Validity

Criterion-related validity was analyzed by comparing completion times of the 4-Corner Elastic Jumping (Kradod Yang) Test with 4 standardized balance assessments: the Flamingo Balance Test, the Y Balance Test, the Star Excursion Balance Test (SEBT), and the Functional Reach Test (FRT). Pearson's correlation coefficients (r) were calculated to examine the degree of association between the Kradod Yang Test and each reference measure.

The results showed low to negligible correlations across all comparisons, indicating that the Kradod Yang Test assesses a distinct dimension of motor performance. The correlation coefficients and their interpretations are summarized in Table 2.

Table 2. Correlation Coefficients between the 4-Corner Elastic Jumping (Kradod Yang) Test and Standardized Balance Tests.

Reference Test	r	Interpretation
Flamingo Balance Test	-0.31	Low
Y Balance Test	0.18	Low
SEBT	0.21	Low
FRT	-0.25	Low

4. User Satisfaction and Field Feasibility

A satisfaction assessment was conducted among 40 youth participants and 30 test administrators to evaluate the feasibility, clarity, safety, and enjoyment of the 4-Corner Elastic Jumping (Kradod Yang) Test. Descriptive statistics (Mean and Standard Deviation) were computed for each group across key domains. The participant's satisfaction focused on enjoyment and clarity, while the administrator's satisfaction emphasized safety and ease of setup during implementation.

The overall findings indicated high levels of satisfaction in both groups, reflecting the practicality and acceptance of the test in real-world applications. The detailed mean scores, standard deviations, and interpretation levels are summarized in Table 3.

Table 3. Comparative Satisfaction Scores for Participants and Administrators.

Group	Key Dimension	Mean (M)	SD	Interpretation
Participants	Enjoyment	4.70	0.52	Very High
Participants	Clarity	4.53	0.60	Very High
Administrators	Ease of setup	4.31	0.66	Very High
Administrators	Safety	4.21	0.77	High

5. Normative Reference Data and Applicability

To establish normative benchmarks and evaluate field applicability, data were collected from 900 healthy Thai youths (270 males and 630 females). Percentile-based reference values were calculated from the completion times of the 4-Corner Elastic Jumping (Kradod Yang) Test to provide practical reference standards for performance classification. Descriptive statistics of test completion times for male and female participants are presented in Table 4, and the percentile-based reference values used for interpretation are shown in Table 5.

Table 4. Mean and Standard Deviation of Fitness Test Results for Youths Using the 4-Corner Kradod Yang Test (n = 900).

Sample Group	Mean (M)	SD	Max	Min
Male Youths (n = 270)	41.83	12.08	74.08	19.54
Female Youths (n = 630)	46.85	10.99	60.58	17.28
Total (n = 900)	45.34	11.55	74.08	17.28

Table 5. Percentile Values of Fitness Test Results for Youths Using the 4-Corner Kradod Yang Test (n = 900).

Percentile Rank (Percentile)	Male (n = 270)	Female (n = 630)	Total (n = 900)
P10	26.42	31.59	29.41
P25	31.32	37.96	36.04
P50	40.37	47.30	45.10
P75	51.76	59.41	57.67
P90	60.04	61.77	60.15

Across all analytical phases, the 4-Corner Elastic Jumping (Kradod Yang) Test demonstrated high empirical rigor and measurement integrity. Content validity (IOC = 0.89) confirmed expert agreement, while intra- and inter-rater reliability (ICC = 0.81; 0.77) supported consistent scoring. Correlation analysis indicated discriminant validity (r = -0.31 to 0.21), confirming that the test measures a distinct construct within dynamic motor competence.

Percentile-based norms derived from 900 participants further validated the test's practicality and ecological suitability for large-scale, low-cost assessment. Overall, the standardized procedures affirm that this culturally rooted Thai folk game can be applied as a reliable and pedagogically valuable field assessment of Dynamic Motor Competence among youth populations.

DISCUSSION

This study aimed to develop and evaluate the 4-Corner Elastic Jumping (Kradod Yang) Test as a culturally grounded and field-based assessment of dynamic motor competence among the youth. The discussion integrates empirical findings with theoretical and pedagogical perspectives to interpret the psychometric robustness, educational feasibility, cultural relevance, and practical applications of the developed test.

1. Psychometric Integrity and Conceptual Innovation

The findings demonstrated strong psychometric integrity of the 4-Corner Elastic Jumping (Kradod Yang) Test. The intra-rater and inter-rater reliability coefficients of 0.81 and 0.77, respectively, met accepted standards for field-based consistency (16), confirming that the procedures were stable, replicable, and supported by clearly defined scoring criteria. The relatively low correlation coefficients ($r = -0.31$ to 0.21) compared with standard balance tests, such as the Flamingo, Y Balance, Star Excursion, and Functional Reach Tests suggest a conceptual distinction rather than a methodological weakness. The new test measures an integrated form of dynamic coordination, agility, and postural control that conventional static or linear tests cannot capture.

This distinctiveness provides empirical evidence of discriminant validity and supports the Dynamic Model of Motor Competence, which conceptualizes motor proficiency as a multidimensional and context-dependent construct (7,28). The ecological structure of the test, requiring controlled and multidirectional movement under elastic tension, replicates real-world motor-learning conditions that enhance adaptability and functional balance. Comparable interpretations were also reported by Marques et al. (19) and Bourke et al. (3) who emphasized the importance of contextualized and performance-based assessments for evaluating true motor ability. Therefore, the 4-Corner Elastic Jumping Test represents a theoretically grounded and practically feasible instrument for assessing dynamic motor competence in naturalistic environments.

2. Pedagogical Feasibility and Cultural Sustainability

The study confirmed the pedagogical and practical value of the test for schools and community programs. Youth participants reported very high satisfaction ($M = 4.56$, $SD = 0.56$), with the highest rating in enjoyment ($M = 4.70$). This finding supports earlier work that identified perceived competence and enjoyment as key motivators for sustained physical activity (Lopes et al., 2021; Lubans et al., 2016). Test administrators also reported high satisfaction ($M = 3.86$), particularly regarding the clarity of setup and ease of administration. The use of low-cost and portable materials such as the elastic bands and lightweight poles further enhances its applicability in resource-limited settings (5,18).

From a cultural perspective, adapting the traditional Thai game Kradod Yang into a standardized motor-assessment tool demonstrates the potential to merge intangible cultural heritage with scientific methodology. This innovation aligns with frameworks emphasizing culturally responsive and sustainable pedagogy (25). The test highlights how recreation-based assessment can foster both motor learning and cultural identity, consistent with Galvani et al. (10), who argued that culturally meaningful play promotes socio-emotional development alongside physical competence.

3. Applicability and Theoretical Implications

The establishment of percentile-based reference data from 900 participants provides a practical benchmark for interpreting motor-competence levels within youth populations. Although not national norms, these data reflect real-world performance variation and developmental differences between groups. Male participants achieved faster mean completion times (41.83 ± 12.08 sec) than females (46.85 ± 10.99 sec), which is consistent with previous findings linking motor coordination differences to physiological and experiential factors (21).

From a theoretical standpoint, the findings extend the conceptual understanding of motor-competence assessment by demonstrating that traditional games can function as ecologically valid indicators of integrated movement coordination (15). Thus, the 4-Corner Elastic Jumping Test contributes to the development of culturally adaptive assessment frameworks that bridge scientific rigor with socio-cultural authenticity. Marques et al. (3) and Sember et al. (25) also highlighted that culturally embedded tasks can better capture authentic movement behaviors shaped by environmental and cultural factors. The present results affirm that the Kradod Yang Test successfully combines ecological validity, inclusiveness, and cultural meaning within a single, field-based framework.

4. Future Research and Practical Directions

Future investigations should expand the validation process of the 4-Corner Elastic Jumping Test through biomechanical and kinematic analysis to identify specific neuromuscular determinants of performance. Longitudinal research could examine its responsiveness to training and developmental change, thereby contributing to the ongoing need for adaptable and responsive youth-assessment tools (8). Broader participant inclusion, such as athletes, rural youth, or individuals undergoing rehabilitation, would also provide further insights into its discriminative potential. Standardizing procedures including elastic resistance, surface conditions, and testing protocols would strengthen inter-site reliability and promote scalability.

Integrating the Kradod Yang Test into the physical-education curricula could serve dual purposes, functioning as both an assessment framework and a learning activity that encourages participation through cultural relevance. This direction aligns with Cruz-León et al. (6) who emphasized the value of inclusive and context-based approaches for promoting active lifestyles and community health.

In summary, the 4-Corner Elastic Jumping (Kradod Yang) Test demonstrates methodological reliability, clear discriminant validity, and high user satisfaction. Beyond its psychometric robustness, the study reinforces the concept of culturally adaptive assessment as a model that harmonizes scientific precision with cultural authenticity. The evidence confirms that traditional recreational practices can be transformed into valid, reliable, and engaging field-based tools for assessing dynamic motor competence. This synthesis advances the global effort to create equitable, accessible, and contextually grounded assessment frameworks that reflect the diversity of human movement in both scientific and cultural dimensions.

CONCLUSIONS

The present study successfully developed and validated the 4-Corner Elastic Jumping (Kradod Yang) Test as a culturally grounded, field-based assessment for evaluating dynamic motor competence among youth. The findings confirmed the test's reliability and consistency, indicating that it can be effectively applied in real-world educational and community environments. Its modest correlations with standardized balance tests reflected a distinct construct of dynamic balance and multidirectional coordination rather than measurement error, affirming its discriminant validity and conceptual uniqueness. Participants and test administrators expressed high levels of satisfaction and engagement, emphasizing that the assessment was safe, enjoyable, and suitable for practical use. The large-scale data provided preliminary percentile-based reference information that demonstrated field applicability without implying national standardization. By adapting the traditional Thai game Kradod Yang into a structured scientific tool, this research highlights the potential of integrating indigenous play with evidence-based approaches to motor competence evaluation. The study contributes to the advancement of culturally adaptive assessment tools that combine movement science, pedagogy, and cultural heritage, offering valuable directions for future refinement, curriculum integration, and long-term promotion of physical literacy and youth well-being.

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Metabolic Adaptations to Training Phases by Male and Female Cross-Country Athletes

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ABSTRACT

McKenna CH, Stover SK. Preparatory endurance training is characterized by high volume training at low intensity. During competitive training, workout intensity is increased significantly to facilitate peak performance. Transitional training is normally associated with a decrease in training volume and intensity to prepare an athlete for the next training cycle. The present study investigated the hypothesis that adaptations in resting metabolic rate (RMR) and respiratory quotient (RQ) would be apparent during distinct phases of an endurance training regimen for collegiate cross-country athletes. Furthermore, it was hypothesized that there would be metabolic differences between male and female athletes at the distinct phases of training. Initial data were collected early in the cross-country season, when the athletes were in the preparatory phase. The second data collection point was during the teams' competitive phase of training, just before the conference championship. The final collection point occurred after the cross-country season had ended. RMR and RQ were determined via indirect calorimetry. Results indicated significant differences between RMR values ($P = .049$), and between RQ values ($P = .034$). Data specifically suggested that females exhibit RMR and RQ values lower than those of their male counterparts, but only during the competitive phase of training. However, when RMR was calculated per kilogram of body weight, significant differences were not detected ($P = .084$). Furthermore, values representing lipid ($P = .166$) and carbohydrate ($P = .210$) utilization per kilogram of body weight did not differ significantly, suggesting that body mass may have a larger impact than sex in determining resting metabolism.

Key Words: Resting Metabolic rate, Respiratory Quotient, Substrate Utilization

INTRODUCTION

For an endurance training regimen to be effective, exercise intensity must be increased at just the right point in training to optimize physiological and biomechanical responses (12,24). Consequently, an annual endurance training schedule is often divided into distinct phases, each with specific objectives. Typically, the phases are classified as preparatory, competitive, and transitional. Preparatory training, also known as the base phase, is characterized by high volume training at low to moderate intensity. This type of training improves endurance capacity, making utilization of fuel substrates more efficient. During competitive training, workout intensity is increased significantly to facilitate peak performance. Finally, transitional training is normally associated with a decrease in training volume and intensity to prepare an athlete mentally and physically for the next training cycle (4,9).

A three-zone model (low intensity, moderate intensity, and high intensity) is often used to describe the pattern of training intensity distribution, although there are no standard criteria for distinguishing between the zones (11). Indicators of intensity may be physiological, like heart rate or blood lactate (25), subjective, like ratings of perceived exertion (8), or performance-based, like race-pace (14). Glycogen stores can be replenished during low-intensity training so that more fuel is available for more intense workouts. Furthermore, low-intensity training involves sustained activity of highly oxidative Type I muscle fibers, which may enhance both aerobic capacity and consumption of glycolytic end products during intense physical efforts (18). Moderate-intensity training is commonly referred to as "threshold training," given that this is the intensity at which blood levels of lactate begin to rise. There is evidence that threshold training can improve physiological responses without inducing excess fatigue (22). High-intensity training is thought to improve various physiological factors, including VO_2 max, which are key to improving performance (15). Moreover, high-intensity workouts minimize hormonal and autonomic stress (21). However, too much high-intensity training can lead to symptoms of overtraining and may have a negative impact on performance (3).

Pyramidal and polarized intensity distributions are the most thoroughly characterized, with both focusing primarily on low-intensity training. A pyramidal pattern will have an athlete spending anywhere from 60% to 90% of training time at low intensity. Most of the remaining time will be at moderate intensity, and an exceedingly small percentage will be at high intensity. A polarized pattern will also require that the majority of training be at low-intensity, but there will be a greater percentage of training at high-intensity than at moderate-intensity (21,26). Runners often use pyramidal distributions during the preparatory phase of training and polarized distributions during the competitive phase (22).

Resting metabolic rate (RMR) is distinct from metabolism during exercise and metabolism after eating. RMR is the primary contributor to total daily energy expenditure that accounts for up to 65% of the daily expenditure (10,27). In both male and female populations, lean body mass tends to be the strongest predictor of RMR, with increased mass associated with an increase in RMR (10). While light, recreational exercise may not significantly influence RMR (20), an escalation in physical activity that leads to a substantial addition of lean body mass can result in an elevated RMR (17). However, if intense training is not accompanied by increased caloric intake, RMR may actually be decreased to conserve energy (28).

Carbohydrates (CHO) and lipids (FAT) are the primary substrates for energy metabolism (1). Several factors, including aerobic fitness, body composition, and sex can affect substrate utilization. While females, in general, may rely more on FAT than males for total daily energy requirements, both males and females tend to shift toward FAT utilization at rest (5,10). Respiratory quotient (RQ) is the ratio of CO_2 exhaled to the amount of O_2 consumed. RQ reflects the relative contributions of CHO and FAT to the oxidative fuel mixture (19). A value of 0.7, for example, would indicate that FAT is the primary fuel source, while a value of 1.0 would indicate that CHO is the primary fuel source.

The present study investigated the hypothesis that metabolic adaptations in RMR and RQ would be apparent during distinct phases of an endurance training regimen for collegiate cross-country and track athletes. Furthermore, it was hypothesized that there would be metabolic differences between the male and female athletes at distinct phases of training.

METHODS

Subjects

This research was approved by the Institutional Review Board of Davis & Elkins College (D&E). The participants were members of the D&E men's and women's cross-country and track teams. All teams competed in the Mountain East Conference, at the Division II level of the NCAA. D&E athletic trainers had medically cleared all athletes to compete in the fall semester of 2024 and the spring semester of 2025. The sample size was generated using a sample size calculator (13). Based on previously reported RMR data for males and females (7,23), a minimum of 18 participants was required to achieve 80% statistical power at an alpha level of 0.05. The data pertaining to individuals who were injured or could not complete the entire five-month study were excluded from the final analysis. A total of 11 males and 7 females, each of whom self-identified, signed consent forms and completed the study.

Procedures

At two specific points in the fall cross-country season (AUG, OCT), and at one point early in the spring indoor track season (JAN), the participants fasted least 8 hours overnight and reported for data collection between 7:00 a.m. and 8:30 a.m. The participants were advised to abstain from any exercise or caffeine for at least 8 hours prior to testing, and they were encouraged to drink enough water to limit dehydration. At the beginning of each data collection session, the participants briefly described their dietary habits (i.e., food restrictions, caloric restrictions, and specific diets). They also reported their weekly running mileage and the relative intensity of the runs. Using a mechanical beam scale, the participants' height was determined during the initial session, and their weight was recorded during each of the 3 sessions.

Initial data were collected early in the cross-country season (AUG) when the athletes were in the preparatory phase. A high volume of weekly mileage was being completed (an average of 43.1 miles for females, 68.6 miles for males) with little to no emphasis on threshold workouts. The second data collection point (OCT) was during the teams' competitive phase of training, just before the conference championship. Weekly mileage remained high (43.0 miles for the females, 68.3 miles for the males), and it was supplemented by routine threshold workouts, as well as lactic VO_2 workouts that combined interval training with lactate threshold training to improve both aerobic capacity and lactic acid tolerance. The final collection point (JAN) occurred after the cross-country season had ended and the indoor track season had recently begun. At this point, training was characterized by a decrease in weekly mileage (38.8 miles for females, 56.3 miles for males) and fewer threshold workouts. Interval work, however, was stepped up in preparation for upcoming track events. According to the participants' informal assessments, this phase was less intense than the competitive phase.

Resting heart rate (rHR) was determined via fingertip pulse oximeter. RMR was assessed by indirect calorimetry. A metabolic cart and canopy system (Cardiopulmonary Exercise Testing System, COSMED, Rome, Italy) was used to analyze gas exchange, allowing determination of RMR. Measured gas exchange data were also used to calculate RQ and estimate the percentage utilization of FAT and CHO as fuel sources. Each subject rested quietly in a supine position under the canopy for a total of 20 minutes. The first 5 minutes served as an acclimation to steady state, a period when the average minute VO_2 and VCO_2 changes by less than 10% and the average RQ changes by less than 5%. Only data from the final 15 minutes of the test were used to determine RMR and RQ.

RMR per kilogram per day was calculated by dividing the daily RMR value by body weight in kilograms. FAT grams used per kilogram of body weight was calculated by first multiplying the daily RMR value by the daily percent FAT utilization value. That product was divided by 9 (as 1 gram of FAT is equal to 9 kilocalories). The resulting quotient was divided by body weight in kilograms to generate a FAT value in grams per kilogram per day. CHO grams utilized per kilogram of body weight were calculated by first multiplying the daily RMR value by the daily percent CHO utilization value. That product was divided by 4 (as 1 gram of CHO is equal to 4 kilocalories). The resulting quotient was divided by body weight in kilograms to generate a CHO value in grams per kilogram per day.

Statistical Analyses

ProStat version 6.5 (Poly Software International, Pearl River, NY) was used for statistical analysis. rHR, RMR, RQ, FAT utilization, and CHO utilization data were subjected to a one-way analysis of variance (ANOVA). Omega squared (ω^2) was calculated for the ANOVA to determine effect size. The Tukey-Kramer test was employed as a *post-hoc* method to compare specific groups in the ANOVA, allowing assessment of both training phase differences and sex-related differences. An alpha level of $P < 0.05$ was regarded as statistically significant. The data are expressed as mean ± standard error.

RESULTS

Descriptive statistics for experimental variables, in aggregate, are found in Table 1. ANOVA indicated no significant differences between resting heart rates measured in male and female participants at time points AUG, OCT, and JAN ($F_{2,53} = 1.04$, $P = .360$). There were significant differences between RMR values ($F_{2,52} = 3.20$, $P = .049$), but when RMR was calculated per kilogram of body weight, significant differences were not detected ($F_{2,52} = 2.61$, $P = .084$). Significant differences were found between RQ values ($F_{2,47} = 3.63$, $P = .034$). However, values representing FAT utilization per kilogram of body weight ($F_{2,46} = 1.87$, $P = .166$) and CHO utilization per kilogram of body weight ($F_{2,46} = 1.61$, $P = .210$) did not differ significantly.

Table 1. Mean ± Standard Error for Experimental Variables at Three Distinct Phases of Training.

Variable	AUG	OCT	JAN
rHR (beats·min^{-1})	47.7 ± 1.3	45.1 ± 1.4	47.2 ± 1.4
RMR (kcal·day^{-1})	1799.1 ± 73.9	1992.7 ± 87.9	1710.8 ± 80.1
RMR (kcal·kg^{-1}·day^{-1})	27.8 ± 0.7	31.0 ± 0.8	27.2 ± 0.9
RQ	0.82 ± 0.03	0.73 ± 0.03	0.85 ± 0.02
FAT Utilization (g·kg^{-1}·day^{-1})	1.6 ± 0.3	2.1 ± 0.2	1.5 ± 0.2
CHO Utilization (g·kg^{-1}·day^{-1})	4.1 ± 0.4	3.4 ± 0 .5	4.2 ± 0.2

rHR = Resting Heart Rate; **RMR** = Resting Metabolic Rate; **RQ** = Respiratory Quotient; **FAT** = Lipid; **CHO** = Carbohydrate; **AUG** = Preparatory Phase; **OCT** = Competitive Phase; **JAN** = Transition to Indoor Track Season.

All effect sizes were small to medium (ω^2 values between .02 and .10), suggesting limited practical application. While no significant differences were found between the training phases in aggregate, *post hoc* analysis of the disaggregated data indicated sex differences for 2 of the variables. The females had significantly lower RMR values than the males, but only during the competitive phase of training (Figure 1). Likewise, the females exhibited RQ values that were significantly lower than those of the males, but that was also only during the competitive phase of training (Figure 2). No significant sex differences were indicated for RMR per kilogram of body weight (Figure 3) or FAT/CHO utilization per kilogram of body weight (Figure 4) during any of the training phases.

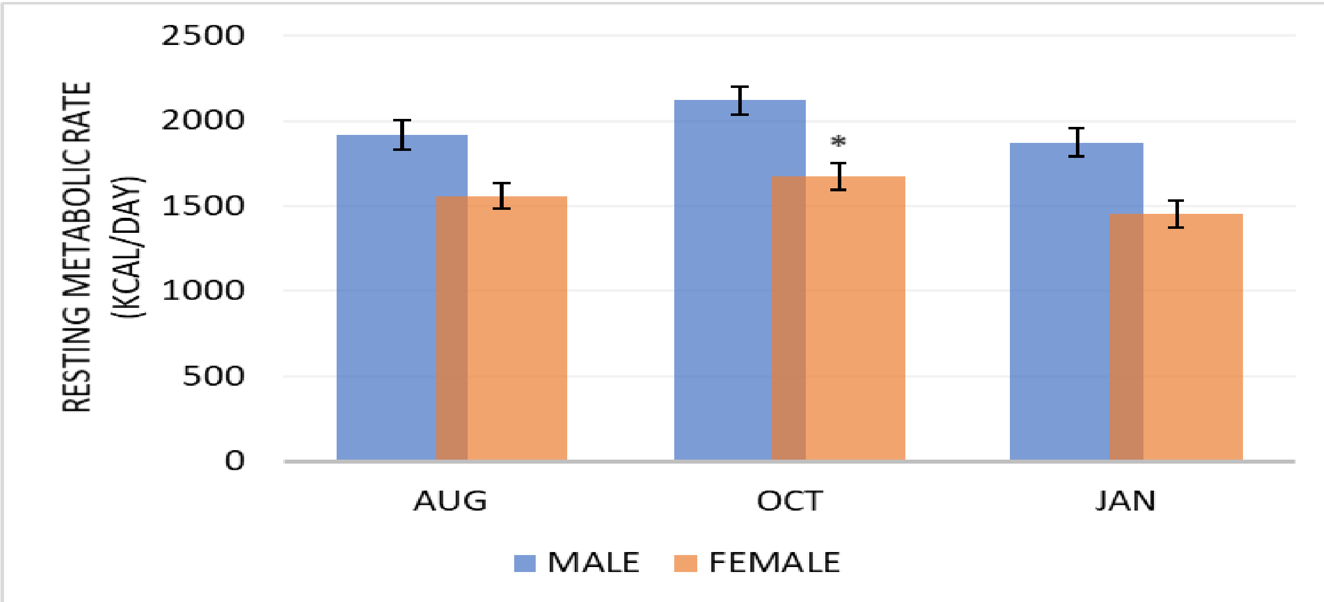

Figure 1. Resting Metabolic Rate (RMR) at Three Distinct Phases of Training (AUG, OCT, JAN). Data are Expressed as Mean ± Standard Error. *Indicates Statistically Significant Difference Between Males and Females during Specific Training Phase.

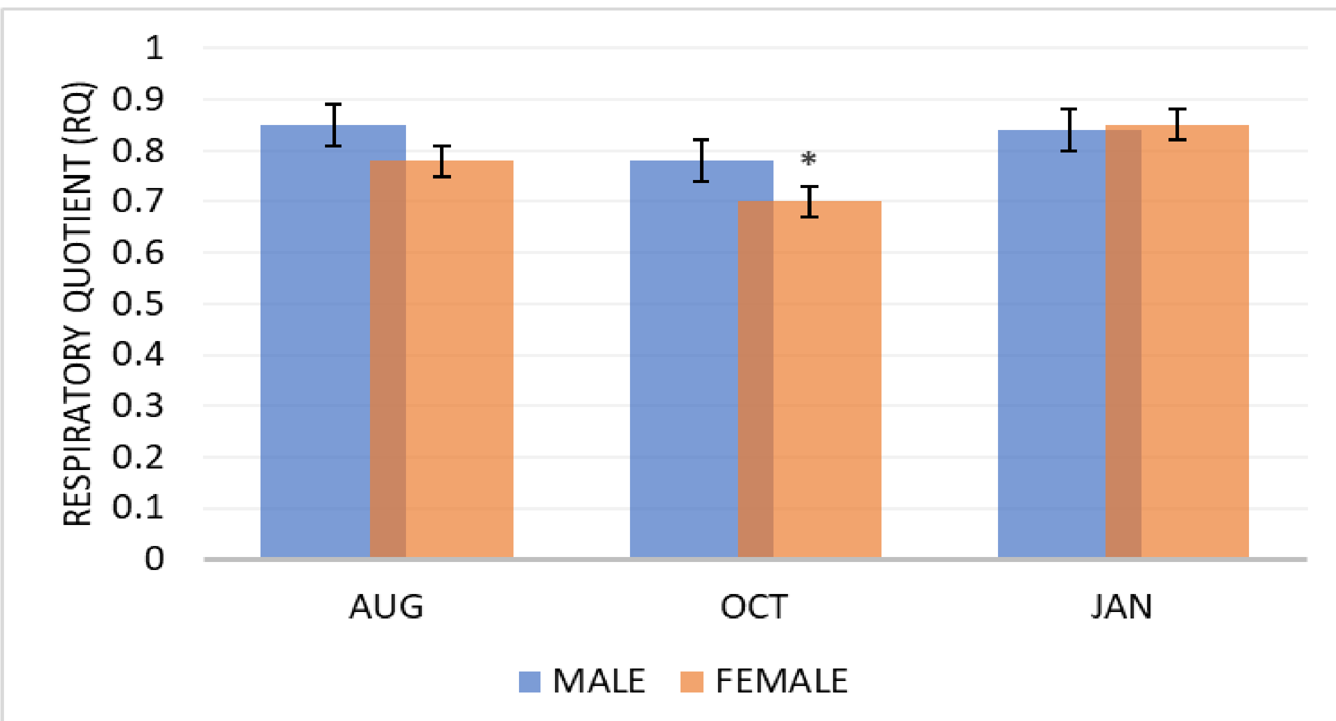

Figure 2. Respiratory Quotient (RQ) at Three Distinct Phases of Training (AUG, OCT, JAN). Data are Expressed as Mean ± Standard Error. *Indicates Statistically Significant Difference Between Males and Females during Specific Training Phase.

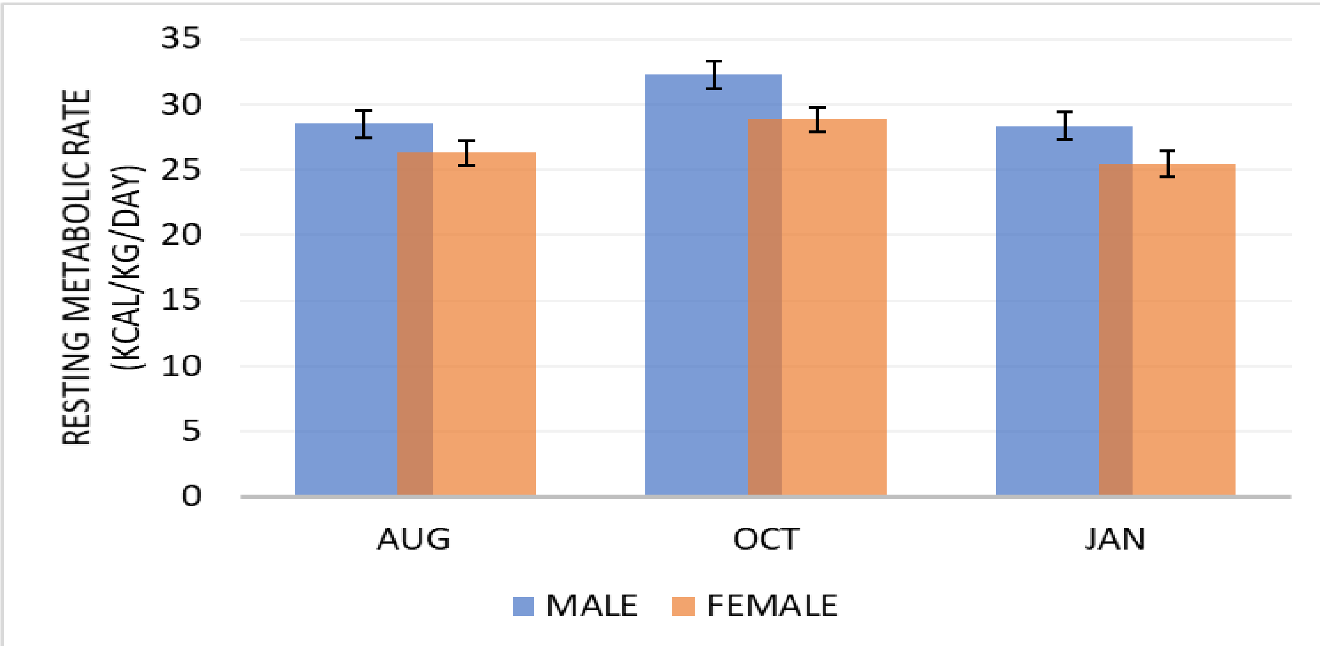

Figure 3. Resting Metabolic Rate (RMR) per Kilogram of Body Weight at Three Distinct Phases of Training (AUG, OCT, JAN). Data are Expressed as Mean ± Standard Error. There Were No Significant Sex Differences at Any Specific Training Phase.

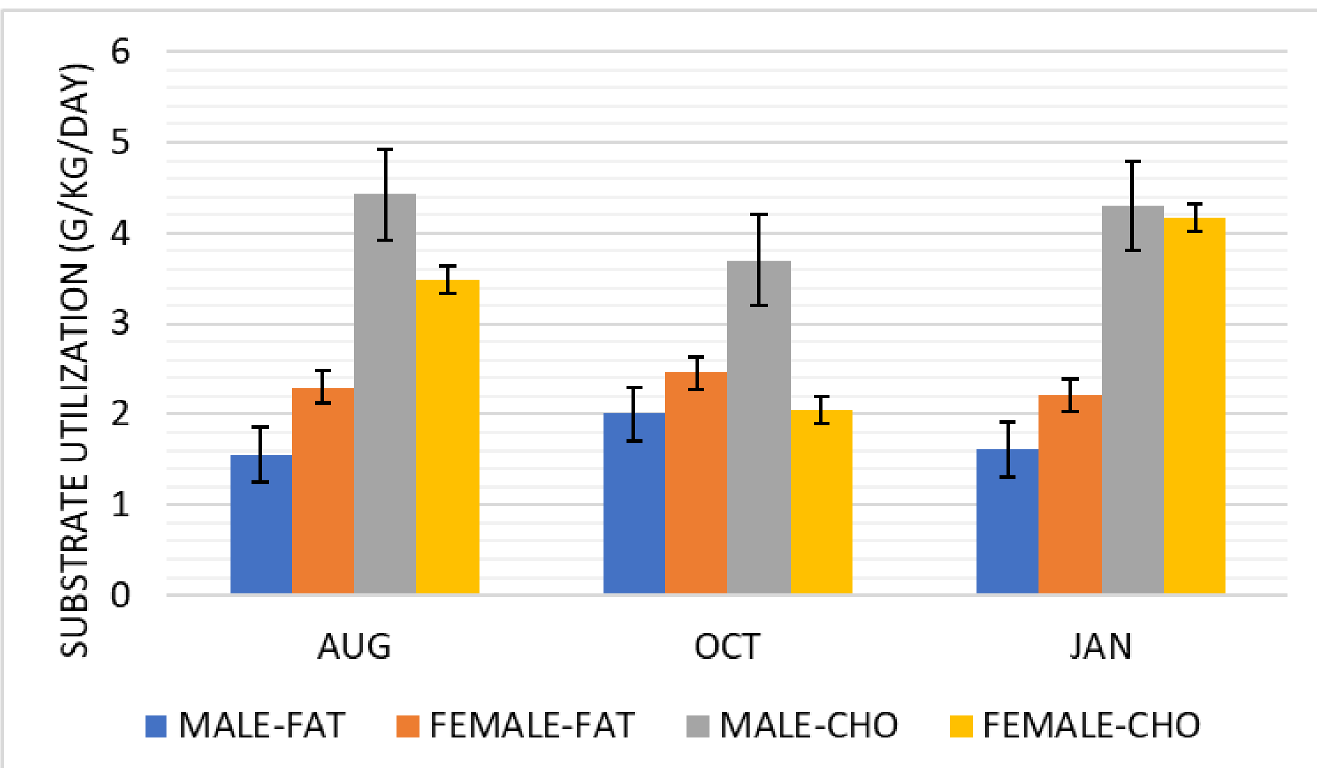

Figure 4. FAT and CHO Utilization in Grams per Kilogram of Body Weight at Three Distinct Phases of Training (AUG, OCT, JAN). Data are Expressed as Mean ± Standard Error. There were No Significant Sex Differences at any Specific Training Phase.

DISCUSSION

We hypothesized that metabolic adaptations would be apparent during distinct phases of an endurance training regimen for collegiate cross-country and track athletes. We also hypothesized that there would be metabolic differences between the male athletes and the female athletes at distinct phases of training.

Resting heart rate (rHR) remained stable throughout the training regimen (Table 1). No significant differences were found between phases or between sexes. A low rHR, or bradycardia, is common among well-trained athletes (6). Our male and female participants consistently exhibited mean rHR values between 45 and 50 beats per minute over the data collection period.

We found that, during the competitive phase of training, the females exhibited RMR values that were significantly lower than those of the males (Figure 1). Once body mass was accounted for, however, the present study indicated no differences in RMR between sexes (Figure 3). Similar findings were reported in a recent study by Jagim et al. (10). Another study (27) demonstrated decreases in RMR during intense training periods, due to early onset fatigue caused by imbalances in energy uptake and expenditure. While we did not conduct strict nutritional assessments, the participants indicated that they had no dietary restrictions (except for a few specific allergens) during the training cycle. Since we saw no significant decreases in RMR per kilogram, there seems to have been sufficient caloric intake to balance the energy expenditure associated with training. It has also been suggested that an escalation in physical activity can increase RMR, if that activity generates an addition of lean body mass (17). We recorded no significant changes in body mass between training phases.

The predicted RQ value for a mixed diet is 0.85 (16). RQ values in the current study were similar to the predicted value, with one exception. The female participants exhibited a mean RQ of 0.7 during the competitive phase of training, a value significantly lower than that of their male counterparts (Figure 2). This might indicate that the females engaged in intense training rely heavily on lipid utilization to meet the body’s total daily energy requirements. Similar findings have been published in previous studies (5,10). When we calculated FAT and CHO utilization in grams per kilogram of body weight, however, we were unable to detect any significant differences between the males and the females (Figure 4). Previous work has indicated that females have a greater proportional area of Type I muscle fibers and a greater capacity for FAT oxidation (2). Although we did not find statistical significance, we did observe a consistent trend of females using more FAT and males using more CHO during each phase of training (Figure 4).

Limitations in this Study

We must acknowledge a few limitations in the current study. First, detailed nutritional data were not collected from the participating athletes. The data related to macronutrient consumption would have allowed a much more nuanced assessment of substrate utilization. Likewise, a more formal assessment of body composition would have allowed a better explanation of any metabolic differences associated with the training phases. Furthermore, the training regimen employed by our athletes did not exactly match the standard phases found in the research literature. While they engaged in a specific preparatory phase, which was characterized by high volume training at low intensity, and a specific competitive phase, which was characterized by a significant amount of training at the lactate threshold, our athletes did not experience the standard transitional phase. Instead of decreasing volume and intensity to recover and prepare for the next cycle, they immediately began training for the indoor track season. While training volume was tapered, the amount of interval work was actually increased. There may have been a larger difference between the second and third phases of training if the standard model was in effect. Finally, there is a small probability for technical errors. Toward the end of the competitive phase, a potentially faulty CO_2 scrubber was replaced on the metabolic cart. Some, but not all, participants were retested. It is possible that some data are inaccurate.

CONCLUSION

Body mass was a major influence on resting metabolism in the current study, more influential than sex. When body mass was accounted for, no sex-related differences were found for RMR or substrate utilization at any phase of training.

ACKNOWLEDGEMENTS

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Congratulations to the D&E men's and women's cross-country teams. Both teams were 2024 Mountain East Conference champions and 2024 NCAA Atlantic Region champions.

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Comparative Effects of Weighted Vest Exercise and Whole-Body Vibration on Pulmonary and Autonomic Function in Older Female Adults

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ABSTRACT

Khaengkhan C, Manimmanakorn A, Manimmanakorn N, Sangartit W, Tantanasest J, Youdprang S, Sumethanurakkhakun W. Aerobic exercise supplemented with a weighted vest and whole-body vibration improved pulmonary functions in older female adults. Regular exercise is well-recognized as a strategy for delaying the risk of age-associated diseases. However, a high proportion of the older population may not achieve sufficient exercise, particularly at an intensity that is sufficient to result in positive adaptation. Therefore, the purpose of this study was to find a more practical way to increase exercise intensity by adding weighted vests to exercise or whole-body vibration on the pulmonary function, heart rate variability, physical performance, and lipid profile in older female adults. Forty-nine females aged 60 to 79 years were randomly assigned to 3 groups: a Control Group (CON; n = 17 received a 60-minute aerobic exercise program, 3 days per week for 8 weeks); a Weighted Vest Group (WV; n = 17 completed the same exercise program but wore a vest); and a Whole-Body Vibration Group (WBV; n = 15 performed the same exercise program with whole-body vibration platform). Lung functions, heart rate variability, physical performance, and lipid profile were assessed before and after the 8-week training. At baseline, the WV Group showed a significant increase VE (3.09 ± 3.79 l/min, P = 0.001), Vt (0.24 ± 0.28 l, P = 0.012), and (MVV 4.17 ± 5.54 l/min, P = 0.041). After training, only the WBV Group showed a significantly improved time main of HRV (SDNN) (8.49 ± 11.73 ms, P = 0.023). While performance in the timed up-and-go test and the single leg to stand test increased in all the Groups, there was no significant difference between the 3 Groups. However, the WV Group showed a significant increase in 6-MWT by 77.71 ± 27.43 m when compared to the CON Group (4.77 ± 39.17 m) and (8.58 ± 47.88 m, P = 0.001, P = 0.002). Furthermore, only the WV Group showed significant reductions in triglyceride (-40.25 ± 47.95 mg.dL^{-1}, P = 0.004) from baseline. Using a combination of light exercise supplemented with a weighted vest or whole-body vibration may be a practical way of increasing exercise intensity sufficiently to improve pulmonary function, heart rate variability, physical performance, and triglyceride levels in the elderly.

Key Words: Elderly, Heart Rate Variability, Lung Function, Triglyceride

INTRODUCTION

Aging represents a progressive decline of physiological function that leads to age-related diseases, such as cardiovascular diseases, pulmonary conditions, and cancer (24). It is estimated by the World Health Organization that the global mortality from cardiovascular disease (CVD) will be 23.6 million people by 2030 (3), and the elderly 65 years and older will account for 82% of all deaths from CVD (38).

Furthermore, the respiratory system undergoes changes linked to aging that generally include physiological and structural concerns, such as the thoracic cage and lung parenchyma that result in abnormal findings on pulmonary function tests. Ventilation is decreased and there are abnormalities in gas exchange. These responses are also linked to the decrease in respiratory muscle strength that results in a decrease in exercise capacity (15). The bottom line is that the physiological changes cause alterations in lung function, which decrease pulmonary remodeling and regenerative capacity along with an increase in sensitivity to acute and chronic lung diseases (6).

Globally, cardiac autonomic dysfunction is a risk factor for CVD, and it is related to several pathologies that include high blood pressure, high triglycerides, hyperglycemia, and diabetes (8). Interestingly, the cardiac autonomic nervous system is able to be a practical measurement by using heart rate variability (HRV), which is a non-invasive technique (28). Lower HRV in the elderly is linked to increased cardiovascular risk, including a higher incidence of heart failure, hypertension, and sudden cardiac death (32).

Regular exercise is well-recognized as an important strategy to prevent the risk of age-associated diseases, and it reduces morbidity and mortality in the general population by decreasing the risk of cardiovascular diseases (39). Fortunately, to prevent or delay the degenerative changes in aging adults, different types of exercises (e.g., resistance and/or aerobic training) have been proposed (7). However, many older adults may not achieve exercise targets due to muscular, ligament, and/or tendon injury. Other adults fail to do so due to their lack of motivation and/or health-related problems. Therefore, exercise programs and other strategies should be developed that are suitable for the elderly to help keep them healthy and essentially free from various diseases. As an example, many studies have combined regular exercise with other strategies, such as whole-body vibration (WBV) and weight vest training to optimize positive health related performance changes.

Whole-body vibration is a form of non-invasive induced mechanical stimulation that uses mechanical vibrations transmitted to the entire body through a vibrating platform. In fact, Park et al. (21) conclude that whole-body vibration training is an efficient training modality for improving performance and health. They indicated that WBV provides an effective option to deliver additional exercise training to improve cardiovascular health in the elderly and disease populations. Previously, Severino and co-workers reported that 6 weeks of WBV training by increased intensity of vibration (25 to 40 Hz of frequency and 1 to 2 mm of amplitude) improved HRV and decreased body fat in obese Hispanic postmenopausal women (25). Wong and co-worker (2016) reported that 8-weeks of WBV with a frequency of 25 to 40 Hz at an amplitude of 1 to 2 mm improved sympathovagal balance and BP in previously sedentary obese postmenopausal women (35).

Similarly, Sverino et al. reported in 2017 that 6 weeks of WBV at a frequency of 25 to 40 Hz at an amplitude of 1 to 2 mm improved heart rate variability in Obese Hispanic Postmenopausal Women (25). Although several studies demonstrated that the acute effects of WBV training activated the sympathetic nervous system (1,31), a previous review demonstrated the positive effect of WBV training (14 to 28 Hz) on respiratory function. Kang and colleagues reported that after 6 weeks of breathing exercise with WBV, there was insufficient evidence to prove the effects of whole body vibration on pulmonary function (13). However, the effects of whole-body vibration training on HRV and lung function are scarce and controversial.

The use of weighted vests in workout programs boosts muscular activation, increases lower extremity strength, and enhances postural control and physical mobility in older adults (29). Training with a weighted vest can stimulate greater cardiovascular adaptations, including enhanced endurance and improved oxygen utilization. A weighted vest can increase the metabolic costs, relative exercise intensity, and skeletal loading during walking; thereby, enhancing the overall physiological demands of the activity (10,22). Adding a weighted vest that is at least 10% of body weight during 8 weeks of circuit training exercise showed a significant decrease in systolic blood pressure in obese subjects. In addition, the benefits of weighted vest exercise on pulmonary function in the elderly were less. We proposed that the use of a weighted vest could potentially preserve muscle mass and bone health through the application of muscular forces or direct mechanical stimulation of mechanoreceptor cells

Despite the growing interest in exercise interventions for older adults, there remains a scarcity of research that has examined the effects of whole-body vibration (WBV) and weighted vest training on pulmonary and autonomic function in this population. To address this gap, the present randomized controlled trial was designed to evaluate the impact of exercise combined with either a weighted vest or WBV on pulmonary function, heart rate variability, lipid profile, and physical performance in older women.

METHODS

Participants

This study was conducted in the Department of Rehabilitation Medicine, Srinagarindra Hospital, Faculty of Medicine, Khon Kaen University, Thailand, where 49 sedentary elderly female participants 60 to 79 years of age with no serious health problems were recruited. All the participants were informed of the experimental protocols and written informed consent was obtained after explaining the objectives, risks, and procedures of the study protocol, which was approved by the Khon Kaen University Ethics Committee for Human Research under the 1964 Declaration of Helsinki and the ICH Good Clinical Practice Guidelines HE651353.

Study Design

Forty-nine participants were randomly assigned to 3 experimental groups. The random allocation sequence was generated by a computer program, and the random sequence was concealed by opaque sealed envelopes. The participants were randomly assigned to 1 of 3 groups: the Control Group (CON; n = 17 received a 60-minute aerobic exercise program, 3 days per week for 8 weeks); the Weighted Vest Group (WV; n = 17 completed the same exercise program but wore a vest); and the Whole-Body Vibration Group (WBV; n = 15 performed the same exercise program with whole-body vibration platform).

A randomized controlled experiment was used to compare body composition and muscle strength, physical performance tests, blood pressure, heart rate, complete blood count, blood sugar, and lipid profile before and after the 8-week intervention period. All the participants were asked to maintain their daily food intake, physical activity, and their normal lifestyle, as well as to avoid other exercises during the experimental period.

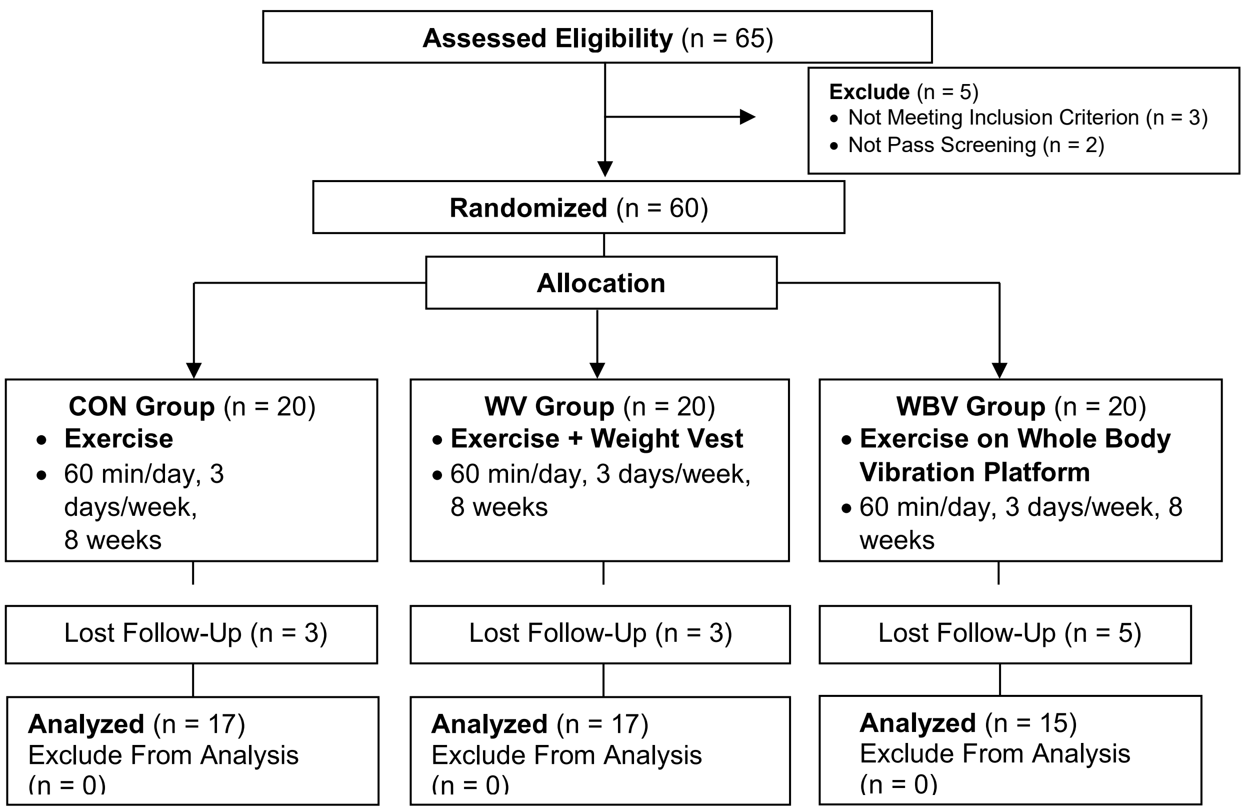

Figure 1. The Consort Diagrammed of this Study.

Experimental Protocol

The participants in the Control Group started with a 5-minute warm-up, followed by 10 minutes of brisk walking. Then, they performed specific strengthening exercises that included 5 postures that included squats, calf raises, wide-stance squats, and Rt/Lt lunges. The participants performed 8 reps/posture interspersed with a 60-sec rest between each posture followed by 8 sets and a 5-minute cool down. Training frequency required 3 days per week for 8 weeks. Before and after each training session, the researchers monitored the participants' blood pressure and resting heart rate. The participants in the Weighted Vest Group completed the same training the Control Group did, except that they wore a weighted vest on the upper part of their body. Small bags of sand were inserted into the pockets around the vest for an even distribution of additional weight. The weight in the vests increased during the 8 weeks (e.g., the first 2 weeks used 5% of individual body weight, then the last 6 weeks the weight was increased to 10% of body weight). The participants in the Whole-Body Vibration Group completed the same warm-up and brisk walk, then they completed the strengthening training exercises on a synchronized vibration platform (Power Plate® Pro5, Performance Health Systems UK Ltd., London, UK) at a frequency of 30 Hz and amplitude of 2 mm.

Outcome Measurement

Lung Function Tests were assessed by using CPET (Quark CPET, Cosmed, ITALY). Before testing, the spirometer was calibrated. All the participants were familiarized with the equipment and procedures before testing. The measurement was taken when the participants were relaxing in a sitting position with a nose clip. The variables measured included: forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), FEV1/FVC ratio, and peak expiratory flow (PEF), forced expiratory flow at 25 to 75% of FVC (FEF25-75%), inspiratory capacity (IC), minute ventilation (VE), tidal volume (Vt), maximal voluntary ventilation (MVV). Each spirometry parameter was accepted when the variation between trials fell to less than ± 5%. The highest value of the 3 best trials were taken as the value for each measurement according to a standard method of the American Thoracic Society and European Respiratory Society (30)

Heart Rate Variable (HRV) was measured with a fingertip pulse wave sensor (SP3000). Before testing, the participants avoided caffeine and alcohol for at least 12 hours and rested for 10 minutes in a seated position in a quiet room. The participants were asked to relax but not fall asleep. A 5-minute recording was taken by a Body photo plethysmograph SA-3000P (Medicore Co., Ltd, Korea). The 5-minute pulse rate was recorded, and then the standard deviation of normal-to-normal RR intervals (SDNN) and root mean square of successive differences in RR intervals (RMSSD) were determined. Power spectral analysis of the pulse recordings was also used to obtain the frequency-domain measures of HRV. The power spectrum was decomposed into its frequency components and quantified in terms of each component's relative intensity (power). The power spectrum was divided into frequency bands, and then the high-frequency band (HF) (0.15–0.40 Hz) and the low-frequency band (LF) (0.04–0.15 Hz) were determined. The HF and LF power and the LF/ HF ratio were used for further analysis.

Cardiovascular Measurement

Systolic blood pressure and diastolic blood pressure were measured by a blood pressure monitor while the participant was in a seated position. All the participants were measured at the same time as possible and had a stabilization time of at least 15 minutes for the participant's arrival and rest before the test. Before the test, all the participants were instructed to continue with their normal activity, avoid strenuous exercise, and relax the arm at the time of cuff inflation [i.e., Mean arterial blood pressure was calculated as. MAP = DBP + 1/3(SBP-DBP)].

Anthropometric and Body Composition
All the participants recorded their body composition, such as body weight, body mass index (BMI), body fat mass, lean body mass, and percentage of body fat (P.B.F) by using a bioelectrical impedance analysis machine (ioi model 353; Jawon Medical, KOREA). The participant's waist circumference and hip circumference were determined using a flexible measurement tape (Measuring tape; Sheico Co., Ltd., Thailand) and, subsequently the measurements were used to calculate the waist-to-hip ratio (WHR).

Static Postural Control and Balance
The participants were evaluated for static postural control and balance by the single leg stand test, which is an essential indicator of fall risk in elderly populations (2). Before testing, the participants were instructed to stand on their preferred leg for as long as possible without any hand-held support. Standing time (in seconds) was recorded from when 1 foot was lifted off the floor and ended when the same foot touched the floor or the other leg.

Time-Up and Go (TUG)
After sitting comfortably in a chair, the participants were instructed to get up from the chair and walk with a comfortable speed to a point on the floor 3 m away. Then, the participants turned around at the 3-m point, walked back to the chair, and sat down to the starting position. Recording time was started when the participant started to rise out of the chair and stopped when back in the original sitting position.

The Six-Minute Walk Test (6-MWT)
A straight-line distance marked by 2 cones that was walked by the participants over a span of 6 minutes was measured. A chair was positioned halfway for the participants to stop to sit if necessary. At the end of 6 minutes, the participants were told to stop and the distances covered during the test was measured in meters (m).

Hematological Parameters
A medical technician drew a 10-mL blood sample by venipuncture from the antecubital vein of the participants who were rested and in a seated position in the morning following a 12-hour fast. Fasting blood samples were gathered a day before the intervention commenced and a day after it was completed. The blood samples were analyzed at the Clinical Laboratory Unit of Queen Sirikit Heart Center of Northeastern Thailand. The analysis included the assessment of total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, and cholesterol levels using a Cobas c702 system (Roche Diagnostics, Company, Ltd., USA).

Statistical Analysis

The data are presented as mean ± standard deviation (SD) of baseline and post-test findings along with change scores. Data normality was evaluated by using the Shapiro-

Wilk Test. Baseline characteristics between the Groups were compared using one-way ANOVA. To determine within-time point differences, paired *t*-tests were applied for normal data or Wilcoxon rank tests would be used if the data were non-normal. A one-way ANOVA was applied to determine significant differences in percent changes between the Groups. A *post hoc* test was used for significant values. All statistical significance was accepted at a P-value of < 0.05. The data analysis was performed using SPSS software version 28.0 (SPSS Inc.; Chicago, IL, USA).

RESULTS

The characteristics of the participants in each of the 3 Groups are presented in Table 1. There were no significant differences in clinical characteristics variables among the 3 Groups at baseline. Lung functions recorded before and after 8 weeks of intervention are presented in Table 2. There were no significant differences in FVC, FEV1, FEV1/FVC, PEF, and IC among the 3 Groups and within each Group following the 8 weeks of the training program. Surprisingly, only in the WV Group showed significant increases in VE (pre = 10.46 ± 4.23, post = 13.54 ± 4.08 l/min, P = 0.04), Vt (pre = 0.66 ± 0.27, post = 0.90 ± 0.25 l, P = 0.012), and MVV (pre = 43.32 ± 4.64 post = 47.49 ± 5.90 l/min, P = 0.041) when compared to baseline. Although VE, Vt, and MVV in the CON Group and the WBV Group showed no significant differences, MVV and WV showed a greater significant increase when compared to the CON and WBV Groups.

Table 1. Clinical Characteristics and Physiological Variables of Participants in the Three Groups.

Parameters	CON (n = 17)	WV (n = 17)	WBV (n = 15)	P-value
Age (years)	66.82 ± 4.23	69.00 ± 5.35	66.07 ± 4.99	0.16
RHR (bpm)	76.18 ± 9.08	75.89 ± 7.08	72.93 ± 7.71	0.43
SBP (mmHg)	133.47 ± 13.57	134.26 ± 10.84	125.40 ± 9.47	0.06
DBP (mmHg)	75.47 ± 7.51	76.58 ± 6.23	73.33 ± 8.90	0.45
MAP (mmHg)	94.80 ± 7.97	95.81 ± 6.26	90.69 ± 7.89	0.12
Height (m)	1.54 ± 0.06	1.52 ± 0.06	1.55 ± 0.06	0.30
Weight (cm)	59.83 ±10.89	57.78 ± 7.83	60.82 ± 10.76	0.66
BMI (kg/m^2)	25.23 ± 3.66	25.01 ± 3.44	24.83 ± 3.32	0.95
WC (cm)	85.15 ± 12.01	87.21 ± 10.99	90.87 ± 10.86	0.36
HC (cm)	96.73 ± 7.71	96.58 ± 7.01	98.73 ± 8.64	0.69
WC/HC (cm)	0.88 ± 0.09	0.90 ± 0.07	0.92 ± 0.11	0.44

The data are presented as mean ± SD. **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group, **RHR**; Resting Heart Rate, **SBP**; Systolic Blood Pressure, **DBP**; Diastolic Blood Pressure, **MAP**; Mean Arterial Pressure, **BMI**; Body Mass Index, **WC**; Waist Circumference, **HC**; Hip Circumference, **WC/HC**; Ratio of Waist Circumference/Hip Circumference.

Heart Rate Variability

The changes in heart rate variability, which are indicated in the time domain and frequency domain that were assessed during the seated position are presented in Table 3. The HRV presented as the time domain at post 8 weeks of intervention, the WBV Group was significantly increased in SDNN (8.49 ± 11.73 ms, P = 0.02) when compared to the baseline while the CON and WV Groups showed no significant changes. Also, there was no significant difference in RMSSD, total spectral (TP), high-frequency component (HF), low-frequency component (LF), LF Norm, HF norm, and LF/HF ratio in the 3 Groups when compared to their baseline and when compared among the 3 interventions.

Physical Performance

The TUG, SLS, hand grip, and 6-MWT recorded before and after the 8-week intervention period in all Groups are shown in Table 4. All Groups show similar improvement in TUG and SLS. However, the WV Group presented a significant increase in 6-MWT by 77.71 ± 27.43 m when compared to the CON Group (4.77 ± 39.17 m) and the WBV Group (8.58 ± 47.88 m, P = 0.001, P = 0.002). However, there was no substantial difference in hand grip in all 3 Groups.

Blood Glucose and Lipid Profile

Blood glucose and lipid profiles in three groups after the 8-week intervention are shown in Table 5. blood glucose, cholesterol, HDL-C, and LDL-C showed no significant differences among the 3 Groups at baseline. Interestingly, only the WV also showed significantly reduced in triglyceride concentrations compared to baseline levels (-40.25 ± 47.95 mg/dL, P = 0.004).

Table 1. Clinical Characteristics and Physiological Variables of Participants in the Three Groups.

Parameters	CON (n = 17)	WV (n = 17)	WBV (n = 15)	P-value
Age (years)	66.82 ± 4.23	69.00 ± 5.35	66.07 ± 4.99	0.16
RHR (bpm)	76.18 ± 9.08	75.89 ± 7.08	72.93 ± 7.71	0.43
SBP (mmHg)	133.47 ± 13.57	134.26 ± 10.84	125.40 ± 9.47	0.06
DBP (mmHg)	75.47 ± 7.51	76.58 ± 6.23	73.33 ± 8.90	0.45
MAP (mmHg)	94.80 ± 7.97	95.81 ± 6.26	90.69 ± 7.89	0.12
Height (m)	1.54 ± 0.06	1.52 ± 0.06	1.55 ± 0.06	0.30
Weight (cm)	59.83 ±10.89	57.78 ± 7.83	60.82 ± 10.76	0.66
BMI (kg/m^2)	25.23 ± 3.66	25.01 ± 3.44	24.83 ± 3.32	0.95
WC (cm)	85.15 ± 12.01	87.21 ± 10.99	90.87 ± 10.86	0.36
HC (cm)	96.73 ± 7.71	96.58 ± 7.01	98.73 ± 8.64	0.69
WC/HC (cm)	0.88 ± 0.09	0.90 ± 0.07	0.92 ± 0.11	0.44

The data are presented as mean ± SD, **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group, **RHR**; Resting Heart Rate, **SBP**; Systolic Blood Pressure, **DBP**; Diastolic Blood Pressure, **MAP**; Mean Arterial Blood Pressure, **BMI**; Body Mass Index, **WC**; Waist Circumference, **HC**; Hip Circumference, **WC/HC**; Ratio of waist Circumference/Hip Circumference

Table 2. Lung Volumes at Body Temperature, Pressure, and Water Vapor (BTPS) in the 3 Groups Before and After the 8-Week Intervention.

Parameters	CON (n = 17)			WV (n = 17)			WBV (n = 15)		
	Pre	Post	Changes	Pre	Post	Changes	Pre	Post	Changes
FVC (l)	1.98 ± 0.25	1.96 ± 0.31	-0.02 ± 0.14	1.92 ± 0.25	1.89 ± 0.26	-0.03 ± 0.12	1.94 ± 0.20	1.83 ± 0.20	-0.11 ± 0.16
FVC % Pred	94.57 ± 10.63	93.07 ± 13.53	-1.50 ± 8.28	92.08 ± 9.67	92.75 ± 9.48	0.67 ± 5.53	85.13 ± 10.55	85.75 ± 11.03	-2.25 ± 11.51
FEV1 (l)	1.58 ± 0.25	1.54 ± 0.29	-0.04 ± 0.11	1.57 ± 0.24	1.57 ± 0.22	0.00 ± 0.08	1.59 ± 0.20	1.53 ± 0.15	-0.06 ± 0.12
FEV1 %Pred	92.67 ± 14.66	89.67 ± .1615	-81.3 ± 18.9	90.75 ± 12.43	93.50 ± 11.13	2.75 ± 6.11	88.38 ± 10.27	86.00 ± 11.30	-2.38 ± 11.61
PEF (l/sec)	3.52 ± 1.18	3.16 ± 1.07	-0.36 ± 0.73	3.50 ± 0.81	2.97 ± 0.91	-0.53 ± 0.84	3.44 ± 1.15	3.07 ± 1.08	-0.37 ± 1.78
FEV1/FVC (%)	83.50 ± 6.49	82.92 ± 6.63	-0.58 ± 4.38	81.77 ± 5.84	81.59 ± 6.24	-0.19 ± 6.13	83.49 ± 7.64	81.51 ± 2.38	-1.98 ± 7.75
FEF25-75% (l/sec)	1.75 ± 0.53	1.66 ± 0.52	-0.09 ± 0.28	1.42 ± 0.44	1.59 ± 0.29	0.17 ± 0.32	1.52 ± 0.61	1.51 ± 0.30	0.14 ± 0.76
IC (l)	1.84 ± 0.59	1.69 ± 0.60	-03.0 ± 84.0	1.82 ± 0.32	1.78 ± 0.31	0.04 ± 0.13	1.88 ± 0.36	1.91 ± 0.28	0.03 ± 0.45
VE (l/min)	12.39 ± 5.16	12.76 ± 5.43	0.38 ± 2.64	10.46 ± 4.23	13.54 ± 4.08*	3.09 ± 3.79	10.26 ± 4.17	10.34 ± 2.36	0.09 ± 3.06
Vt (l)	0.69 ± 0.24	0.68 ± 0.24	0.00 ± 0.14	0.66 ± 0.27	0.90 ± 0.25*	0.24 ± 0.28	0.81 ± 0.36	0.99 ± 0.51	0.18 ± 0.33
MVV (l/min)	48.89 ± 12.86	42.88 ± 13.88	-6.01 ± 4.33	43.32 ± 4.64	47.49 ± 5.90*	4.17 ± 5.54[a]	51.43 ± 5.54	56.72 ± 5.89*	5.29 ± 5.08[a]

The data are presented as mean ± SD, **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group.

*Significant difference changes in pre and post, [a]Significant difference compared with the CON Group.

Table 3. The Heart Rate Variability (HRV) in 3 Groups Before and After 8-Week Intervention.

Parameters	CON (n = 17)			WV (n = 17)			WBV (n = 15)		
	Pre	Post	Changes	Pre	Post	Changes	Pre	Post	Changes
Time Domain									
SDNN (ms)	24.49 ± 11.17	28.21 ± 10.85	3.72 ± 11.13	25.79 ± 10.10	27.41 ± 11.42	1.62 ± 8.09	22.81 ± 6.39	31.30 ± 12.23*	8.49 ± 11.73
RMSSD (ms)	18.45 ± 7.90	17.31 ± 6.46	-1.14 ± 5.94	18.35 ± 6.33	18.16 ± 7.35	-0.18 ± 6.73	21.21 ± 9.23	24.79 ± 9.07	3.00 ± 11.99
Frequency Domain									
TP (ms^2)	5.99 ± 0.96	6.28 ± 1.13	0.29 ± 1.09	6.15 ± 0.86	6.09 ± 0.90	-0.06 ± 0.91	5.81 ± 0.77	6.26 ± 0.95	0.45 ± 0.89
VLF (ms^2)	5.42 ± 1.12	5.81 ± 1.21	0.39 ± 1.29	5.58 ± 0.81	5.31 ± 1.08	-0.27 ± 1.22	5.28 ± 0.48	5.74 ± 1.05	0.46 ± 0.92
LF (ms^2)	4.0 ± 1.1	4.06 ± 1.08	0.08 ± 0.96	4.4 ± 1.2	4.56 ± 1.10	0.17 ± 1.19	4.1 ± 0.8	4.34 ± 1.19	0.25 ± 1.09
HF (ms^2)	3.98 ± 0.88	4.01 ± 0.92	0.03 ± 0.75	4.37 ± 1.13	4.26 ± 1.10	-0.10 ± 0.88	4.23 ± 0.63	4.55 ± 0.85	0.32 ± 0.83
LF Norm (ms^2)	55.00 ± 16.87	52.72 ± 16.91	-2.28 ± 24.04	51.20 ± 17.95	55.96 ± 19.76	4.76 ± 24.40	43.91 ± 19.76	43.81 ± 18.09	-0.11 ± 23.67
HF Norm (ms^2)	46.24 ± 16.83	43.98 ± 14.32	-2.25 ± 22.25	47.90 ± 17.32	43.96 ± 19.08	-3.93 ± 23.68	58.17 ± 16.50	51.91 ± 19.60	-6.26 ± 22.10
LF/HF Ratio	1.37 ± 0.75	1.37 ± 0.80	-0.01 ± 1.10	1.31 ± 0.71	1.36 ± 0.88	0.05 ± 1.10	0.74 ± 0.36	1.01 ± 0.90	0.27 ± 0.82

The data are presented as mean ± SD, **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group, **SDNN**; Standard Deviation of RR Interval, **RMSSD**; Root Mean Square of the Successive Difference, **TP**; Total Spectral HRV, **VLF**; Very Low-Frequency component of spectral HRV, **LF**; Low-Frequency component of spectral HRV, **HF**; High-Frequency component of spectral HRV, **LF/HF ratio**; Ratio of Low-Frequency component and High-Frequency component of spectral HRV, *Significant difference changes between pre and post.

Table 4. The Physical Performance in 3 Groups Before and After 8-Week Intervention.

Parameters	CON (n = 17)			WV (n = 17)			WBV (n = 15)		
	Pre	Post	Changes	Pre	Post	Changes	Pre	Post	Changes
TUG (sec)	13.28 ± 1.63	9.35 ± 1.15	-3.94 ± 1.03*	11.27 ± 2.29	6.36 ± 1.56*	-4.91 ± 2.72	9.91 ± 1.68	7.29 ± 0.78*	-2.62 ± 1.36
SLS (sec)	12.97 ± 9.35	30.77 ± 17.47	17.79 ± 15.64*	14.45 ± 10.26	39.32 ± 27.52*	24.86 ± 25.46	17.29 ± 12.58	35.32 ±19.64*	18.02 ± 23.50
Hand Grip (kg)	17.29 ± 3.15	17.11 ± 3.88	-0.18 ± 2.14	19.29 ± 3.65	19.86 ± 3.79	0.57 ± 2.18	19.71 ± 3.41	19.88 ± 2.93	0.17 ± 2.48
6MWT (m)	334.06 ± 46.46	338.83 ± 48.58	4.77 ± 39.17	339.37 ± 20.18	417.08 ± 30.00*	77.71 ± 27.43 [a,b]	390.67 ± 39.43	399.25 ± 45.22	8.58 ± 47.88

The data are presented as mean ± SD, **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group, **TUG**; Time Up and Go Test, **SLS**; Single Leg Stand Test, **6MWT**; 6-Minute Walk Test, * Significant difference changes between pre and post, [a]Significant difference compared with CON, [b]Significant difference compared between WV and WBV.

Table 5. Blood Glucose and Lipid Profiles in 3 Groups Before and After 8-Week Intervention.

Parameters	CON (n = 17)			WV (n = 17)			WBV (n = 15)		
	Pre	Post	Changes	Pre	Post	Changes	Pre	Post	Changes
Blood Glucose (mg/dL)	95.29 ± 11.15	97.00 ± 13.63	1.71 ± 5.58	94.31 ± 8.63	96.31 ± 8.34	2.00 ± 6.19	95.86 ± 7.73	94.57 ± 8.29	-1.29 ± 5.21
Cholesterol (mg/dL)	197.87 ± 39.43	204.53 ± 45.43	6.67 ± 22.59	223.12 ± 34.89	220.82 ± 37.71	-2.29 ± 14.07	227.08 ± 43.56	224.15 ± 52.21	-2.92 ± 27.24
Triglyceride (mg/dL)	148.27 ± 58.72	151.40 ± 54.29	3.13 ± 40.76	150.86 ± 57.98	116.31 ± 30.03*	-40.25 ± 47.95	138.08 ± 49.15	134.00 ± 58.08	5.67 ± 40.66
HDL-C (mg/dL)	50.67 ± 10.87	49.80 ± 10.87	-0.87 ± 6.53	48.18 ± 13.31	49.00 ± 14.71	0.82 ± 5.43	53.08 ± 15.08	52.31 ± 12.50	-0.77 ± 8.99

The data are presented as mean ± SD, **CON**; Control Group, **WV**; Weight Vest Group, **WBV**; Whole-Body Vibration Group, **HDL-C**; High-Density Lipoprotein, **LDL-C**; Low-Density Lipoprotein, *Significant difference changes in pre and post.

DISCUSSION

An increase in mortality has been associated with reduced lung function (5). It is widely recognized that physical training programs can positively influence respiratory health in older adults. This study investigated how combining exercise with either a weighted vest or whole-body vibration (WBV) affects pulmonary function in older women. The participants engaged in identical workouts for 8 weeks, 3 times per week, with each session lasting 60 minutes. The key outcome revealed that incorporating a weighted vest during exercise significantly enhanced pulmonary function, such as VE, Vt, and MVV as well as reduced triglyceride levels. In contrast, the WBV Group experienced improvements in autonomic function, and both intervention Groups demonstrated better physical performance, as evidenced by gains in the TUG and SLS tests.

The findings of the present study are consistent with previous studies that reported the influence of exercise can produce a significant improvement in pulmonary parameters. In general, regular exercise, including both aerobic and strengthening exercises, has been shown to improve lung function, such as FEV1 and FVC in older adults with or without respiratory disease (37). A similar observation was also made by Wen and coworkers who found that 8 weeks of aerobic exercise combined with strengthening exercise training improves lung function in the elderly with disabilities (33). Ferraro et al. (9) reported that an 8-week inspiratory muscle training program in older adults significantly increased inspiratory muscle function that improved pulmonary capacity and physical performance. Moreover, Mei and Chang (19) found that regular aerobic exercise improved pulmonary function that enhanced VE.

Wearing a weight vest during exercise is a form of resistance training that increases mechanical stress during exercise (14). Previously, Kim and colleagues found that 8 weeks of circuit training with a weighted vest was effective in improving VO_2 max and maximum power output. They suggested that training with a weighted vest may promote greater Vt, allowing for more air to be inhaled and exhaled per breath, which is important for effective oxygen exchange (14). Weighted vest training during exercise has been linked to improvement in VE since it increases the workload and stimulates respiratory muscles that leads to an increase in oxygen uptake and utilization (20). Furthermore, exercise with a weight vest consistently increases VE, Vt, and MVV because of higher metabolic and respiratory demand. A weight vest increases the energy cost and workload of exercise on the respiratory muscles, which leads to a greater inspiratory effort during exercise (26).

The results of this study align with previous research findings regarding the impact of whole-body vibration (WBV) on pulmonary function. Yang et al. (37) conducted a systematic review in 2016 and concluded that WBV did not significantly enhance lung function. Similarly, Cardoso et al. (4) found that although a 12-week WBV program improved walking distance in patients with chronic obstructive pulmonary disease (COPD), it did not lead to changes in pulmonary function. WBV also showed no effect on lung function in individuals with cystic fibrosis (23). Gloeckl et al. (11) reported comparable cardiopulmonary responses in COPD patients when comparing exercise with and without WBV.

Aging is associated with a decrease in heart rate variability (HRV). The effect of 8-week training demonstrated that only the WBV Group showed a significant increase in the time domain (standard deviation of RR interval: SDNN), but the CON Group and the WV Group showed no changes when compared to their baseline. However, the frequency domain of HRV was presented with no substantial changes among the 3 Groups. SDNN index increase indicates increased HRV and consequently, a decreased cardiac risk for the elderly (27). The findings of this study corroborate the studies of Severino and colleagues (25). They found that 6 weeks of whole-body vibration exercise significantly increased R-R interval, which improved HRV in obesity. Moreover, Wong et al. (35) reported that the effects of 8 weeks of whole-body vibration (25 to 50 Hz) were improved sympathovagal balance and blood pressure in obese postmenopausal women. The potential mechanisms of whole-body vibration on heart rate variability may potentially be mediated by angiotensin II and nitric oxide (NO). Whole-body vibration training has been found to improve endothelial function and increase in nitric oxide (NO) levels, which NO may play a role in cardiac autonomic function by increasing vagal and decreasing sympathetic activity.

Physical performance, as measured by the Timed Up and Go (TUG) test and single-leg stance, improved across all 3 Groups following the training period. However, no significant differences were observed between the Groups. The six-minute walk test (6MWT), a straightforward tool for evaluating cardiovascular fitness and exercise capacity (18), revealed that the Weighted Vest (WV) Group achieved the most notable improvement, unlike the Control Group and the Whole-Body Vibration Group. Prior research has shown that weighted vests can enhance muscle strength (20) and physical performance in older adults (30). Supporting this finding, Jessup et al. (12) found that a 32-week program combining weighted vest walking and strength training led to substantial gains in 6MWT distance. These results suggest that exercising with added load increases muscular stress, thereby elevating metabolic and mechanical demands (20). This heightened demand may stimulate cardiovascular adaptations that ultimately improves 6-MWT outcomes.

In the Weighted Vest Group, exercise leads to a decrease in triglyceride levels, which aligns with previous research by Yang et al. who observed that a 3-month program combining aerobic and resistance training lowered both LDL cholesterol and triglycerides (36). Similarly, LeMura et al. (16) reported notable decreases in plasma triglycerides following an 8-week regimen of thrice-weekly workouts at 70 to 75% of HRmax for 30 minutes. Mann et al. (17) also found consistent triglyceride reductions in their meta-analysis of resistance training studies. The current study suggests that incorporating additional weight during exercise may amplify metabolic responses. Potential mechanisms include increased muscle mass, enhanced insulin sensitivity, and elevated post-exercise oxygen consumption that contribute to a greater fat oxidation (17). However, these mechanisms warrant further investigation.

CONCLUSIONS

Participating in an 8-week exercise program while wearing a weighted vest appears to be the most effective strategy for enhancing pulmonary function, cardiovascular fitness and lowering triglyceride levels. The whole-body vibration (WBV) program demonstrated the greatest benefit in improving cardiac autonomic regulation, as evidenced by increased SDNN values.

Limitations in this Study

This study has several limitations. First, the participants were not instructed to record their daily dietary intake, although they were asked to maintain their regular eating routines throughout the intervention. Second, assessments of lower-body muscle strength were not conducted. Instead, upper-body strength was measured using handgrip tests, which may not accurately reflect the effects of the predominantly lower-body exercise regimen, such as walking. Therefore, further research is necessary to confirm and expand upon these findings.

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