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A Comparison Between the Effects Of Backward Resisted Sprint and Sprint Bounding on Sloped Surface Training on Muscular Fitness and Acceleration Ability in Young Male Sprinters Ages 15-18 Years

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This study is a comparison between the effects of backward resisted sprint and sprint bounding on sloped surface training on muscular fitness and acceleration ability in young male sprinters ages 15-18 years. Twenty-four male athletes were randomly divided into 3 groups of 8 participants each: Group 1 did backward resisted sprint training. Group 2 did sprint bounding on sloped surface training, and the Control Group followed a regular sprint training program. The intervention lasted 6 weeks, with 2 training sessions per week. Speed performance was evaluated at 10, 20, 30, and 40 meters, and maximal power output was measured before and after the 6-week training period. The data were analyzed using mean and standard deviation (SD), one-way analysis of variance (ANOVA) to compare between Groups, and Bonferroni *post hoc* tests to identify pairwise differences, with a significance level set at $P < .05$. Paired-sample *t*-tests were used for within-group comparisons. The results revealed that after 6 weeks of training, there were statistically significant differences among the 3 Groups in all variables, including sprint speed at 10, 20, 30, and 40 meters and maximal power output. The Backward-Resisted Sprint Training Group showed significantly greater improvements in all performance parameters compared with both the Inclined Bounding Sprint Training Group and the Control Group. Furthermore, the Inclined Bounding Group demonstrated better development than the Control Group in the 10- and 20-meter sprint performance. Therefore, it can be concluded that resisted backward sprint training is a more effective training method for enhancing acceleration ability and muscular performance in young male sprinters 15 to 18 years of age.

Keywords: Acceleration Ability, Backward Resisted Sprint Training, Muscle Fitness, Sprint Bounding on Sloped Surface Training, Sprint Training

Introduction

The development of highly capable sprinters has become increasingly important, particularly in regards to the training methods appropriate for young athletes. Training designed for adults may not be suitable for children and adolescents, who are still undergoing physiological development. Improper training methods can negatively affect body structure and increase the risk of injury. Key components in developing sprinting speed include acceleration, maximum velocity, and the ability to maintain top speed. Among these, the initial acceleration phase from the start is critical to competitive performance. Several studies have reported that muscular power is correlated with acceleration during the first 5 to 10 meters, and athletes with superior acceleration tend to achieve better competitive results. Therefore, training for short-distance runners, especially 100-meter sprinters who start from starting blocks, must emphasize posture and body mechanics during the start phase to achieve efficient acceleration toward maximum velocity.

Charoen Krabuanrat (9), who teaches in the Department of Sport Science at Kasetsart University, stated that one of the main problems in youth sports training today is the use of adult training methods with children. Although this may initially enhance performance, it often leads to negative effects. Overly intensive training can harm the physiological development of young athletes whose bones are not yet fully developed, thus potentially causing joint problems and increased risk of injury. In young runners, the optimal time to introduce strength and power training programs is between 15 and 18 years of age (4). During this stage, rapid growth occurs and their testosterone levels increase significantly that leads to greater muscle mass and force production (6). The study by Kavaliauskas et al. (8) found that short-term uphill sprint interval training for only 2 weeks led to early adaptations in both the muscular system and the nervous system, particularly in terms of increased lower limb power and sprint ability. This indicates uphill running can stimulate muscle activity in a manner that is close to resistance training, while offering advantages in joint safety and reduced impact forces during exercise.

Similarly, Alemu and colleagues (1) investigated the effects of uphill training on maximal velocity and overall performance in middle-distance runners using a randomized controlled trial. The results demonstrated that uphill training significantly enhanced maximal velocity and overall physical performance, which indicated that such training not only develops muscular power but also improves movement efficiency and high-speed running capabilities. Clearly, the studies by Alemu et al. (1) and Kavaliauskas et al. (8) highlight the importance of uphill training as an effective method for developing “maximal velocity and muscular power” that aligns with the principles of resistance and backward running training, which focus on neuromuscular adaptations to enhance sprint performance and short-distance running ability.

Although resistance training, weight training, plyometric exercises, and uphill sprinting are used to develop acceleration ability, Sanphasit (15) found that developing sprint training models using different incline angles (3°, 6°, and 9°) influence running speed differently. Combined or complex training that integrates resistance sprinting with bounding sprints on an inclined surface enhances explosive power, force production, and acceleration ability in young sprinters. Thus, improved running speed is largely attributed to resistance or weight training. Both muscular strength and power should be developed simultaneously. Ebben and Watts (3) suggested that weight training should precede plyometric exercises to minimize injury risk and prepare the musculoskeletal system for high-impact loading. Uthoff and colleagues (16) found that resisted sprint training using backward sled towing in youth athletes effectively improved sprint speed and acceleration.

For many young athletes, success in sports competitions depends heavily on their ability to run fast over short distances (5). Running performance is enhanced by combining lower-body strength with rapid stretch–shortening cycle function. Acceleration and power production naturally increase during growth and maturation (12). However, sprinting ability can be further improved through specific training methods. Resisted sprint training is widely used by speed and strength coaches because it provides both technical and biomechanical benefits. This specialized training method has proven effective for youth, mid-, and post-pubertal athletes. Training over 6 to 8 weeks with loads ranging from 20% to 55% of body mass (BM) results in increased acceleration and muscular power (12).

Monaghan and Cochrane (10) examined the effects of backward resisted sprinting (BRS) in male adolescent athletes and found that training with loads reducing maximal speed by 35% and 55% significantly improved 5-meter sprint performance. BRS training also enhanced lower limb strength and vertical jump height more effectively than forward resisted sprinting (FRS) and control groups. Empirical evidence supports the effectiveness of these methods. Uthoff et al. (16) reported that both backward and forward sprint training over an 8-week period improved sprint speed and muscular power among male adolescents 13 to 15 years of age, with backward sprinting yielding superior performance in short-distance sprints and vertical jump ability.

In a subsequent study, Uthoff et al. (16) found that backward resisted sprinting (BRS) produced greater gains in 10- and 20-meter sprint performance compared to forward resisted sprinting (FRS) and control groups, while also enhancing countermovement-jump height and leg stiffness. Similarly, Sammoud et al. (14) observed that both backward and forward sprint training improved general physical performance—including power, speed, and change-of-direction ability—among female handball players. Extending this line of evidence, Jawed et al. (7) demonstrated that backward resisted sprint training (BRST) was particularly effective in enhancing 10-meter sprint performance, lower-limb strength, and explosive power during the acceleration phase, which is crucial in short-distance sprinting.

Research has shown that uphill sprinting and resisted sprinting, such as sled towing, effectively enhance power and acceleration, especially among athletes aged 15 to 18, the optimal period for developing muscular strength and speed. Various sprint training methods, such as sprint-resisted and sprint-assisted training have been designed and modified to enhance athletic speed. Hence, the purpose of this study was to compare the effects of backward resisted sprint training and bounding uphill sprint training on muscular performance and acceleration ability in male short-distance runners 15 to 18 years of age, with the goal of supporting the development of Thai sprinters toward higher performance levels.

Research Objectives

1. To study the effects of backward resisted sprint training and sprint bounding on sloped surface training on muscular performance and acceleration ability in young male sprinters 15 to 18 years of age.
2. To compare the effects of backward resisted sprint training and sprint bounding on sloped surface training on muscular performance and acceleration ability in young male sprinters 15 to 18 years of age.

Materials and Methods

The population of this study consisted of young male sprinters 15 to 18 years of age who were from various institutions across Thailand. The sample group in this study consisted 24 young male sprinters between 15 and 18 years of age. They were selected through purposive sampling from the Bangkok Sports School. The participants were randomly assigned using simple random sampling into 3 groups: (a) the **Experimental Group 1** (n = 8) resisted backward sprint training; (b) the **Experimental Group 2** (n = 8) sprint bounding on sloped surface training; and (c) the **Control Group** (n = 8) conventional sprint training.

The Inclusion Criteria consisted of young male sprinters: (a) who were 15 to 18 years of age engaged in regular training for competitions; (b) who had no injuries that would affect participation in the training program; (c) who were not using anabolic steroids or any prohibited substances; (d) who possess basic strength sufficient to perform a squat with a load equal to at least 1.5 times their body weight, rising to a standing position with knees bent at 90 degrees; (e) who were willing to participate voluntarily after signing the informed consent form; and (f) who were not participating in any other research studies or exercise programs during the study period. ***The Exclusion Criteria*** consisted of: (a) withdraw consent or unwilling to continue participating in the research; (b) attend fewer than 80% of the total training sessions or less than 15 sessions in total; and (c) unable to continue due to unavoidable circumstances, such as illness or injury.

The research instruments used for data collection consist of: (a) Timing Gates (Swift Speed Light), which is manufactured by Swift Performance, Australia and used for measuring acceleration ability; (b) a Muscle Power Testing Machine (FT-700 Power System), manufactured by Fitness Technology, Australia. It is used for measuring muscle performance; and (c) instruments for the Training Programs, that included the Backward Resisted Sprint Training Program (Weeks 1–2: 20% of Body Mass (BM) resistance load; Weeks 3–4: 30% of Body Mass (BM) resistance load, and Weeks 5–6: 40% of Body Mass (BM) resistance load. Also, the Sprint Bounding on Sloped Surface Training Program (Weeks 1–2: Incline angle of 3 degrees; (Weeks 3–4: Incline angle of 6 degrees, and Weeks 5–6: Incline angle of 9 degrees).

This research project was reviewed and approved by the Thailand National Sports University Research Ethics Committee, with certification number SCI 014/2024. This certification certifies that the research project, "Comparison of the Effects of Backward Resistance Running Training and Incline Jumping Training on Muscular Fitness and Acceleration in Sprinters," for athletes 15 to 18 years of age can be conducted in accordance with research ethics principles. The research must strictly adhere to established conditions to protect the participants. The Research Ethics Committee approved the research according to the documents and research protocol submitted by the principal investigator. The approval was valid from April 17, 2024, to April 16, 2025. Any amendments or deviations from the original research project had to be reviewed by the Research Ethics Committee before commencing to ensure the safety and rights of the participants.

The data were analyzed to examine and compare the effects of resisted backward sprint training and inclined surface bounding sprint training on muscle performance and acceleration ability of young male sprinters aged 15 to 18 years. Statistical analyses were performed using computer software with the following procedures: (a) calculate the mean and standard deviation to describe the general characteristics of the data; (b) determine the Index of Congruency (IOC) for the validation of the research instruments; (c) analyze differences between the groups using a One-Way Analysis of Variance (One-Way ANOVA) and perform pairwise comparisons using the Bonferroni method, with the level of statistical significance set at 0.05; (d) analyze within-group differences using the paired-sample *t*-test; and (e) the level of statistical significance was set at 0.05 for all analyses.

RESULTS

Table 1 Comparison of Mean, Standard Deviation, and One-Way ANOVA Results after 6 Weeks of Training on Muscle Performance and Acceleration Ability among Experimental Group 1, Experimental Group 2, and the Control Group.

Variables	After 6 Weeks of Training							
	Experimental Group 1		Experimental Group 2		Control Group		F	P *P<.05
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD		
1. Speed 0–10 m (m/s)	6.48	0.78	5.70	0.47	5.57	0.34	6.17	.01*
2. Speed 0–20 m (m/s)	7.27	0.48	6.55	0.63	6.37	0.46	6.59	.01*
3. Speed 0–30 m (m/s)	7.74	0.51	7.20	0.38	7.05	0.32	6.23	.01*
4. Speed 0–40 m (m/s)	7.94	0.38	7.60	0.22	7.57	0.28	3.76	.04*
5. Peak Power (W/kg)	63.75	1.80	58.71	1.51	54.82	1.29	67.10	.00*

Interpretation of Table 1 After 6 weeks of training, the comparison of mean differences among the 3 Groups showed statistically significant differences at the .05 level in all measured variables. The findings indicate that Experimental Group 1 (backward resisted sprint training) demonstrated better acceleration ability and higher muscle performance than the Experimental Group 2 (sprint bounding on sloped surface training) and the Control Group.

Figure 1 presents the mean speed values from the starting point to 10, 20, 30, and 40 meters after 6 weeks of training in Group 1, Group 2, and the Control Group.

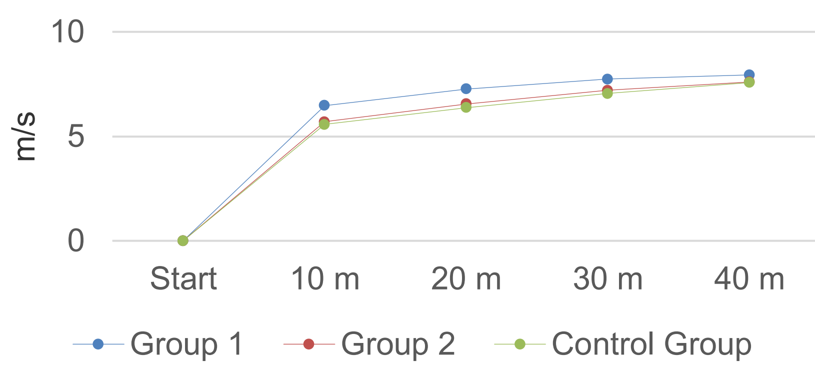


Figure 2 presents the mean peak power (W/kg) after 6 weeks of training in Group 1, Group 2, and the Control Group.

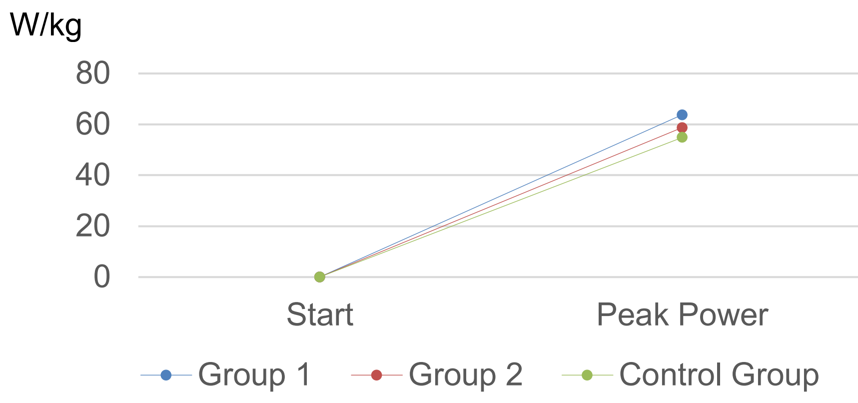


Figure 3 presents a comparison of the mean speed values from the starting point to 10 meters before and after 6 weeks of training in Group 1, Group 2, and the Control Group.

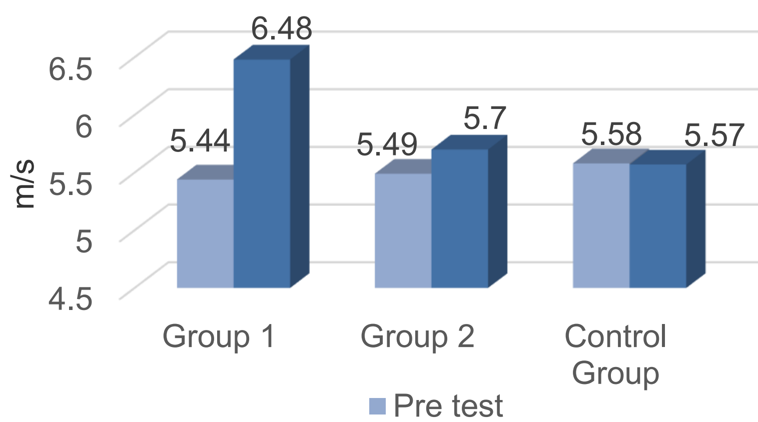


Figure 4 presents a comparison of the mean speed values from the starting point to 20 meters before and after 6 weeks of training in Group 1, Group 2, and the Control Group.

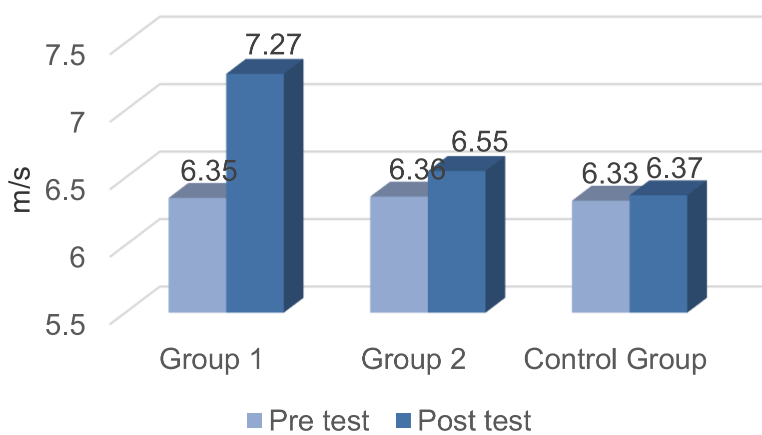


Figure 5 presents a comparison of the mean speed values from the starting point to 30 meters before and after 6 weeks of training in Group 1, Group 2, and the Control Group.

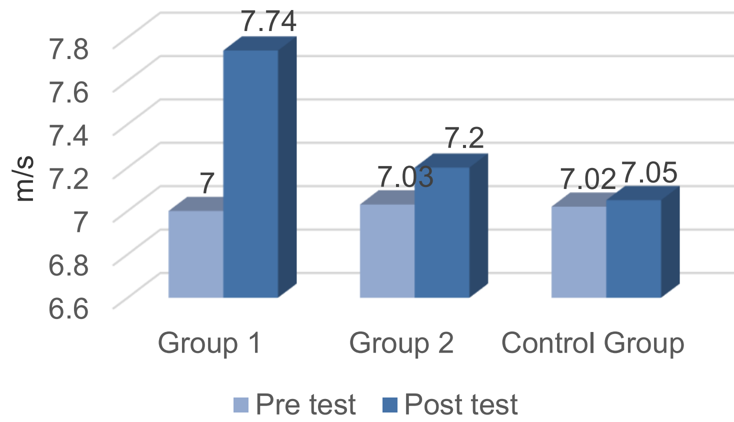


Figure 6 presents a comparison of the mean speed values from the starting point to 40 meters before and after 6 weeks of training in Group 1, Group 2, and the Control Group.

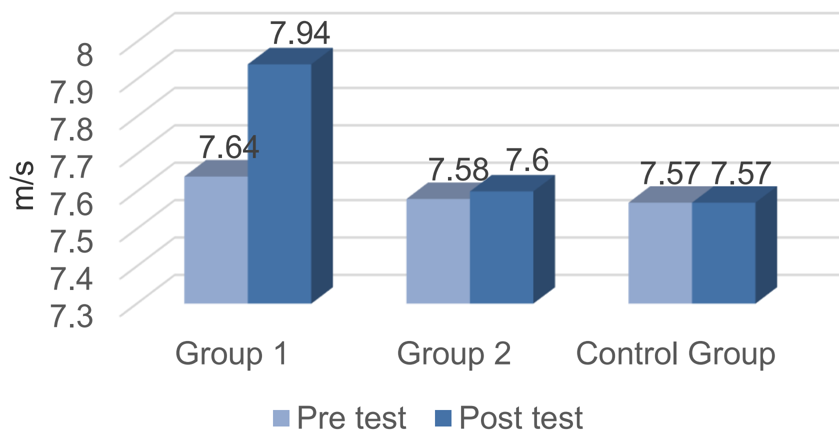
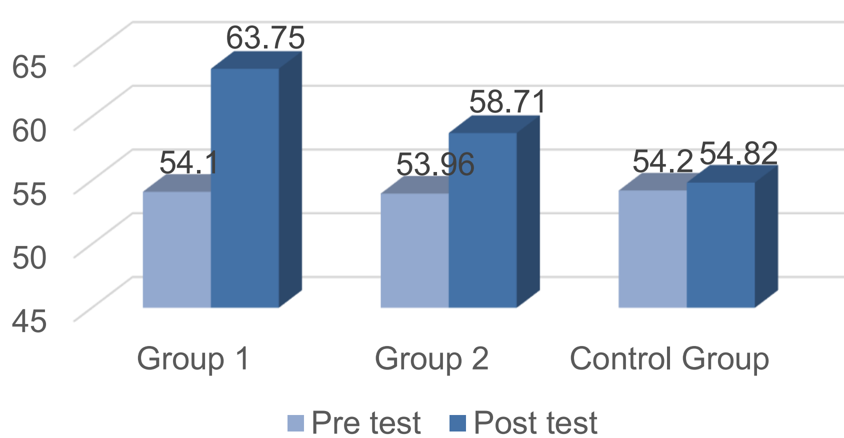


Figure 7 presents a comparison of mean muscle power (W/kg) before and after 6 weeks of training in Group 1, Group 2, and the Control Group.



DISCUSSION

The results indicate that muscle power and sprinting ability, including sprint speed over 10 m, 20 m, 30 m, and 40 m, and peak power significantly improved after 6 weeks of training. These findings align with Krabuanrat (9), who stated that strength training induces neuromuscular adaptations, including increased motor unit firing rate, recruitment, and muscle fiber cross-sectional area, resulting in the enhancement of force production. Similarly, Krabuanrat (9) noted that speed enhancement training through resistance or overload exercises increase muscular effort during movement. In this study, resisted backward sprinting and inclined plyometric sprinting effectively strengthened relevant muscle groups and improved the function of white muscle motor units.

This aligns with Sappasit (15), who reported that different incline angles (3°, 6°, and 9°) during sprint training influence sprint speed, and that combining resistance training with incline sprints develops explosive power and force production, which determine acceleration ability in youth sprinters. Bompa (2) emphasized that athletes need to develop muscular power for competition, particularly starting power and acceleration power that involves primarily fast-twitch fibers. Ross et al. (13) found that groups training with combined speed and resistance training for 7 weeks significantly improved sprint performance over 30 m when compared to speed-only or resistance-only training groups.

The findings of this study show that Experimental Group 1 outperformed Experimental Group 2 and the Control Group in muscle power and sprinting ability, with significant improvements observed after 6 weeks of training. Resisted backward sprinting effectively enhanced sprint speed and acceleration by combining lower-body strength and rapid stretch-shortening cycle function. Winnick and Short (17) noted that speed development involves increasing muscle stretch force, neuromuscular coordination, strength, contraction ability, and anaerobic energy production.

Uthoff et al. (16) reported that backward and forward sprint training improved sprint performance and jumping ability compared to conventional sprint training, with backward sprinting particularly enhancing 10 m and 20 m performance. Backward sprinting also promotes postural stability, balance, increased step frequency, calf muscle strength, and reduces joint load on knees and ankles. The findings of Sammoud et al. (14) indicated that both backward and forward sprint training conducted over an 8-week period improved the overall physical performance of female handball athletes, including power, speed, and change-of-direction ability, with no significant differences between the two training methods. This result is consistent with the findings of Jawed et al. (7), who compared backward resisted sprint training (BRST), forward resisted sprint training (FRST), and a control group among university students. They found that BRST was more effective in enhancing short-distance sprint performance, particularly over 10 meters, during the acceleration phase, which is crucial in short sprints such as the 100-meter dash. Moreover, BRST improved lower limb strength and explosive power, which are key components for increasing sprinting speed over short distances.

These findings are consistent with the review by Myrvang et al. (11) that examined the longitudinal effects of resisted and assisted sprint training. The review concluded that both resisted and assisted sprint training have long-term positive effects on the athletes' speed, muscular strength, and movement efficiency since the resisted sprint training stimulates neuromuscular adaptations specific to the direction and force applied during sprinting movements. In summary, the results from these studies indicate a consistent trend showing that both backward and forward sprint training, particularly BRST, effectively enhances sprint speed, acceleration ability, and muscular power, which are critical factors for improving athletic performance in various sports.

Krabuanrat (9) highlighted that key components of sprint development include reaction time, starting ability, acceleration to maximal speed, stride length and frequency, and anaerobic muscular performance. However, athletes should first build foundational strength due to high training intensity, especially in youth athletes. Basic movement skills are essential for optimizing both skill and physiological performance.

CONCLUSIONS

With regards to the between-group results, after 6 weeks of training, the mean values of sprint speed over 10 m, 20 m, 30 m, and 40 m were significantly different among Experimental Group 1, Experimental Group 2, and the Control Group at the .05 level. Pairwise comparisons revealed that Experimental Group 1 had significantly higher mean sprint speeds over 10 m, 20 m, 30 m, and 40 m compared to Experimental Group 2 and the Control Group, except for the 40 m distance between Experimental Group 1 and Experimental Group 2. Experimental Group 2 did not show significant differences in mean sprint speeds compared to the Control Group at all distances.

After 6 weeks of training, the mean peak power values differed significantly among the 3 Groups at the .05 level. Pairwise comparisons indicated that Experimental Group 1 had significantly higher peak power than Experimental Group 2 and the Control Group. Additionally, Experimental Group 2 also had significantly higher peak power than the Control Group.

With regards to the within-group results, the Experimental Group 1 showed significant improvements in mean muscle power and sprinting ability after 6 weeks of training compared to pre-training at the .05 level, except for sprint speed over 40 m, which improved but was not statistically significant. The Experimental Group 2 showed significant improvements in mean muscle power and sprinting ability after 6 weeks of training compared to pre-training at the .05 level, except for sprint speed over 30 m and 40 m, which improved but was not statistically significant. The Control Group showed slight improvements in muscle power and sprinting ability after 6 weeks of training, however, the changes were not statistically significant at the .05 level for any variable.

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Golf Recreational Exercise for Enhanced Survivorship (GREENS) in Prostate Cancer Survivors: Protocol for a Feasibility and Efficacy Pilot Study

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ABSTRACT

Cai G, Pinski J, Michener LA, Schroeder T, Kirages D, Yamada K, Katz J, Moore J, Tu J, and Salem GJ. Golf Recreational Exercise for Enhanced Survivorship (GREENS) in Prostate Cancer Survivors: Protocol for a Feasibility and Efficacy Study. The GREENS is a golf-based multimodal recreational activity program designed to improve physical function, psychosocial wellbeing, and quality of life in prostate cancer survivors undergoing hormone therapy. The purpose of this study is to examine the feasibility of the GREENS program, and secondarily to examine the efficacy of the program on physical function and psychosocial wellbeing. Fifteen prostate cancer survivors between the ages of 55 and 85 will be recruited for an 18-week, delayed-entry-control, golf intervention study. The participants will be assigned to 3 groups of 5 and have baseline (T0) physical and psychosocial assessments, followed by a 5-week control period. The assessments will be repeated at the start (T1) and at the end (T2) of the 10-wk golf intervention. Comparisons between the T0 and T1 will be used to examine the stability of the outcome measures; whereas, comparisons between T1 and T2 will be used to assess the feasibility (e.g., safety, adherence, and acceptability) and efficacy of the golf program on physical function, psychosocial wellbeing, and quality of life. Findings from the study will be used to optimize the golf program for the design of an expanded randomized controlled trial.

Key Words: Exercise Oncology, Prostate Cancer, Quality of Life, Recreational Activities

INTRODUCTION

Prostate cancer (PCa) is the 2nd most common cancer in males, behind skin cancer (23,38,52). It has a 5-year relative survival rate of 96.8% and the most common age range at diagnosis is between 55-74 years (39). Hormone therapy (e.g., androgen deprivation therapy [ADT] and/or combination of ADT and androgen receptor blockers) is a cornerstone treatment for PCa but these pharmacological interventions can create detrimental effects to health and overall quality of life (QoL) during survivorship (29,41). These effects, which are amplified by the aging process and other comorbidities such as metabolic syndrome and cardiovascular disease include: 1) declined physical capacity; 2) loss of muscle strength and function; 3) increased fatigue; 4) inactivity; 5) increased BMI; 6) decreased bone health; 7) increased fall and fracture risk; 8) impaired cognitive function; 9) increased anxiety and depression; 10) reduced sleep quality; 11) incontinence; and 12) poorer overall QoL (3,11,43,56,63,64). Taken together, it is imperative to explore intervention strategies to improve health quality in PCa survivors who have the potential to lead long and meaningful lives (63).

Exercise oncology is a growing area of research, and activity-interventions in PCa survivors are known to mitigate symptoms and reduce the chances of recurrence (11,43,63). Current exercise guidelines, put forth by the American College of Sports Medicine (ACSM) in 2018, recommend that survivors should "be as physically active as their age, abilities, and cancer status will allow", which supports the importance of exercise adherence and prescription flexibility (43). Exercise has demonstrated consistent improvements in physical function, fatigue, anxiety, depressive symptoms, and health-related QoL in PCa survivors, with evidence primarily in traditional resistance and aerobic exercise programs (11,28,39). Within the past few decades, however, *recreational* activities and sports**,** including dragon boat racing, soccer, group-based walking, and group yoga, have also demonstrated improved physical and psychological outcomes (6,7,24,32). Furthermore, the group-based, recreational nature of these activities appears to promote better adherence and longer-term engagement as compared to non-group based, aerobic and resistance training (10,24,58). Most notably, soccer programs conducted in Danish men with PCa resulted in numerous health benefits while successfully retaining participants in the program through longitudinal follow-ups (1-year and 5-year) (6,7,32,58-61).

While exercise is known to improve health and wellness in PCa survivors, only approximately 12% of PCa survivors meet the ACSM exercise guidelines of 150 minutes of moderate-intensity or 75 minutes of strenuous-intensity exercise per week, and twice weekly resistance exercise (5,21). Exercise program adherence is affected by barriers specific to the PCa treatment and recovery, however, several facilitators, such as structured group exercise, exercise variety, and attitudes and exercise intention, have been reported to influence participation (46). Thus, structured and group-based multimodal recreational activities (MRAs) appear to be promising tools to improve health measures, while also increasing physical activity, exercise, and social engagement.

Golf is a unique MRA that combines physical activity and cognitive tasks in an outdoor and social environment (17,27,36,37). Over the last two decades, researchers have explored the therapeutic effects of golf on numerous aspects of health including mortality rate, cardiovascular and metabolic health, physical function (static and dynamic balance, strength, flexibility), cognitive function (memory and attention), psychosocial health (quality of life, socialization, stress, confidence), and long-term physical activity engagement (17,20,27, 36,37,51,52). For example, in 2009, a Swedish study with a cohort of over 300,000 found that golfers had 40% reduction of mortality rate compared to the non-golfing counterparts, regardless of age, gender, or socioeconomic status (20). In 2018, a 20-year cohort study of British men reported golf, along with a few other activities in midlife, were among the strongest predictors of physical activity participation in old age, which empirically demonstrated the anecdotal observation of golfers' long-term adherence to the activity (1,51,52). In 2022, golf was recommended by a group of international uro-oncologists to improve wellbeing among PCa survivors (41). Despite the positive evidence from various disciplines and countries, no formal investigation has been carried out to examine the feasibility and efficacy of a prescribed golf program specifically designed for PCa survivors.

General physical activity and specific modes of exercise have consistently demonstrated health benefits in PCa survivors undergoing androgen-related hormone therapy (9,39,61,64); however, methods to improve the long-term engagement of PCs survivors in physical activity continue to be a challenge. The GREENS study will use a golf-based MRA to address this challenge. The study has two primary purposes: 1) to test the feasibility (e.g., safety, adherence, and acceptability) of the program; and 2) to examine the program's efficacy on health outcomes, including quality of life, physical function, and psychosocial wellbeing. We hypothesize that such a group-based, supervised, recreational activity program would be feasible with low adverse events, high adherence, high acceptability, and improvement in important health measures, such as physical function and QoL.

METHODS

Subjects

The GREENS study was approved by the University of Southern California (USC) Institutional Review Board (#HS-23-00366), the Clinical Investigations Committee, and registered at Clinicaltrials.gov (ID: NCT06500169). Fifteen PCa survivors undergoing hormone therapy were recruited from the University of Southern California Norris Comprehensive Cancer Center Prostate Cancer Clinic, Keck hospital, and i2b2 informatics data warehouse, which allows researchers to access contact information of patients who had record of having the specified study condition (e.g., prostate cancer diagnosis). The study inclusion/exclusion criteria are listed in Table 1.

Table 1. Inclusion and Exclusion Criteria.

Inclusion	Exclusion
• First and primary diagnosis of localized or metastatic prostate cancer • Currently receiving androgen deprivation treatment (ADT) and/or androgen receptor blocker for ≥ 6 months • Older adult male: 55-85 years old	• Second cancer diagnosis (excluding non-invasive skin cancers) or bone metastases • American Joint Committee on Cancer (AJCC) stage IVA and IVB prostate cancer diagnosis • Prostatectomy less than 6 months prior to study enrollment • Dementia and Alzheimer's Disease assessed via the Telephone Memory Impairment Screen • Symptomatic cardiovascular disease, active angina, uncontrolled hypertension (Systolic blood pressure >160 or diastolic blood pressure >90, high resting HR >90), symptomatic orthostatic hypotension • Unstable asthma, exacerbated chronic obstructive pulmonary disease (COPD)

• The ability to stand independently without external support • No or minimal golf experience (played <5 time in the past 10 years) • English speaking	• Rheumatoid arthritis, unstable ankle, knee, hip, shoulder, or wrist joints • History of injury or orthopedic operation within the last 6 months • Movement disorders (e.g., Parkinson's disease or other neurological disorders), hemiparesis or paraparesis • Severe vision or hearing problems

Sample Size

The primary focus of this pilot study is to evaluate feasibility; thus, a formal power analysis was not required. A target of 15 participants was based on methodological recommendations for pilot studies (typically 12 to 30 participants) and consistent with prior exercise oncology and golf-based interventions (18,19,27,32,34). This size allows reasonable precision for feasibility outcomes while maintaining close supervision and detailed monitoring of safety events.

Procedures

The GREENS study is a delayed-entry, within-subject, intervention study, with 3 assessment timepoints (Figure 1). In accordance with the Consolidated Standards of Reporting Trials (CONSORT) statement extension for pilot and feasibility studies and the ORBIT Model for developing behavioral treatments, the primary focus is on assessing the feasibility and efficacy of the *GREENS* program to provide essential data for the design of a future, fully-powered randomized control trial (8,16,18,19,29). After baseline assessment (T0) and a 5-week delayed-entry control period, another assessment (T1) will take place immediately prior to the 10 weeks of golf instruction and complimentary exercises. At the completion of the 10-wk intervention, there will be a final post-intervention assessment (T2). Fifteen PCa survivors are to be enrolled in 3 groups/waves of 5 participants (Figure 3). The training sessions will be held twice weekly, for 90 min, and led by a Professional Golf Association (PGA) certified instructor and study Research Associates. Training sessions include golf-specific warm-up exercises (e.g., body-weight squats), PCa-specific exercises (e.g., Kegels) and golf-related training (rules, putting, chipping, swinging, etc.).

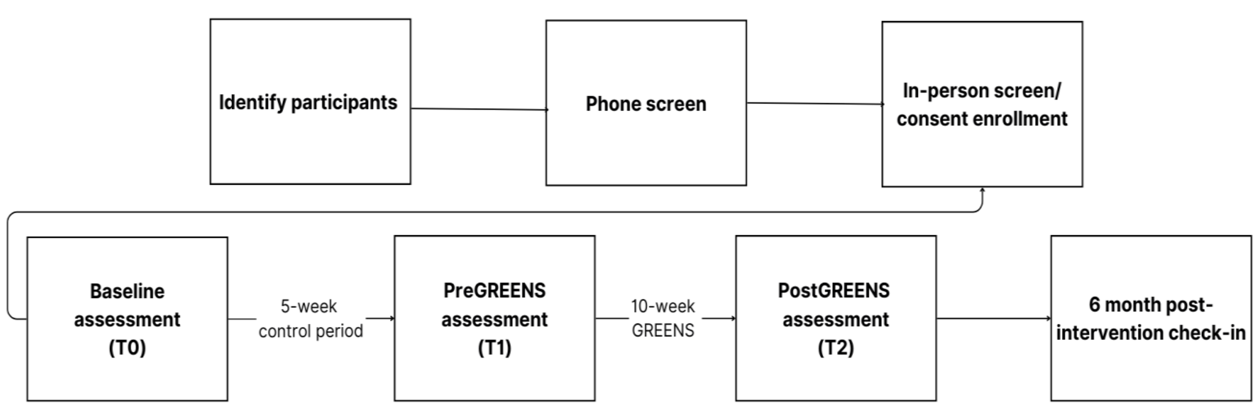

Figure 1. Planned Participant Flowchart.

Golf Program

The program was designed to be as safe and effective as possible for PCa survivors with no or limited experience in the sport. The program is progressive in nature and includes PCa-specific pelvic floor muscle (PFM) training (see details in following section), golf-specific preparatory exercises, driving range, putting, and course activities (Figure 2). The emphasis of the program is on physical activity and social support, rather than golf performance. To prepare the participants for the physical challenges of golf-related activities, initial training will commence with 45 min of golf-specific-exercises and PFM-training. The duration of the warm-up period, putting, and driving range activities will decrease progressively from week 1 to week 8 so that by week 8 onwards, only 10 min of these activities will take place, and the remaining time will be on the course. The on-course play commences during week 6, with two-three holes of play. During each successive week, the driving range time will be reduced, and the number of holes played will increase until the participants can play 9 holes by week 10. Similar multimodal golf program designs have been tested in older male military veterans by Du Bois et al. (17) and in healthy older adults by Kanwar et al. (27), and they were proven safe, feasible, and adherent.

Figure 2. Gold Program Breakdown and Example Pictures from Previous Studies.

Weeks	Conditioning	Golf Training
1-3 (Phase 1)	Golf Specific Drills + Exercises + Pelvic floor muscle Exercises 45 minutes	Introduction to Golf Swing Training 45 minutes
4-7 (Phase 2)	Golf Specific Drills + Exercises 20-30 minutes	Golf Play 2-5 holes
8-10 (Phase 3)	Dynamic Warm Up 10 min	Golf Play 6-9 holes

2 sessions/week; 90 minutes/session

Preparatory Exercises

Urinary incontinence is a common and bothersome treatment side-effect for PCa survivors (3,44,48,52). However, PFM training has proved to be effective in improving continence recovery and will be used in the current study (3,46,54). At the start of the program, the participants will be trained in how to perform proper PFM contractions. They will be given instructions, using common PFM training terminology including “shorten the penis and imagine trying to stop the flow of urine” to promote dorsal movement and urethral closure, and “squeeze your anus as if you were holding back gas” to promote activation of the anal sphincter muscle (50,54). Once the sensation of PFM contraction is established, the participants will be instructed to perform body weight squats, standing leg raises, quadruped hip extension, supine bridges, and swing loading drills. Instructions will also be given for the participant to hold a PFM contraction through ball impact during the golf swing. The intention is to deliver high volume, supervised PFM training, which has been shown to be effective in improving continence (3).

Aim 1: Feasibility

As a pilot/feasibility study, the primary purpose is to determine whether the program is feasible in PCa survivors by assessing safety, adherence, and acceptability. *Safety* of the program will be determined by assessing the rate and severity of the adverse events (AEs) that occur throughout the training sessions. The program will be considered safe if there are less than 3 mild AEs, which is defined as Grade 3 or below according to National Cancer Institute's Common Terminology Criteria for Adverse Events V5 (13). *Adherence* will be determined by assessing the attendance rates and program compliance of the participants. The program will be considered adherent if the participants attend more than 80% of the training sessions and complete over 90% of the instructed activities within each session (14). *Acceptability* regarding the program will be assessed using Physical Activity Enjoyment Scale-8 (PACES-8), an 8-item 7-point Likert scale enjoyment questionnaire and a validated 4-item 7-point satisfaction questionnaire (25,35). The PACES-8 demonstrate high internal consistency (Cronbach's alpha =0.92-0.91), moderate test/retest reliability (Intraclass Correlation Coefficient [ICC] = 0.61), and has been validated in multiple languages in sedentary and community-dwelling older adults (25,35). These questionnaires will be assessed at the end of week 3 (Phase 1), week 7 (Phase 2), and week 10 (Phase 3) of the program (Figure 2).

A study exit interview will be conducted at T2. It will include 7-point Likert scale questionnaires regarding the willingness to continue in a similar program and the willingness to recommend the program (10). The program will be considered feasible: 1) if over 80% of the participants report high average enjoyment (PACES-8 score ≥50, 90%) and satisfaction (satisfaction questionnaire score ≥25, 90%) across the 3 program phases; 2) if over 80% of the participants report high likelihood of continued participation in (question score ≥6); and 3) if over 80% of the participants report they would recommend the program to others (question score ≥6) (14,35).

Aim 2: Efficacy

Quality of Life (QoL) efficacy will be assessed using the *Functional Assessment of Cancer Treatment – Prostate, FACT-P*. This self-report questionnaire has been used to assess QoL in aerobic, resistance, and high intensity interval training exercise-intervention studies in PCa survivors (2,15,26). The FACT-P is a validated measure in PCa survivors with high internal consistency (Cronbach's alpha = 0.92), Minimal Detectable Change of 8.5- to 9.7-point difference, and Minimal Clinical Important Difference (MCID) of 6- to 10-point difference (15).
Physical Capacity will be assessed using the *Short Physical Performance Battery, SPPB*. The SPPB includes measures of balance, lower-extremity strength and power, and gait speed. It has been used in PCa survivors to examine the effectiveness of home-based walking and resistance training, and technology-mediated walking and resistance exercise interventions (44,47). The SPPB is a validated measure in older-adult PCa survivors with reported ICC of 0.92 and MDC of 0.8 points (45,48).
Urinary Continence will be determined using the International Consultation on Incontinence Questionnaire-Urinary Incontinence Short Form, ICIQ-UI SF. It has been used in PCa survivors to examine PFM training interventions in improving continence (3,32,44). The ICIQ-UI SF is a validated measure in PCa survivors with an ICC of 0.73 and MDC of 4.9-point difference (32).
Psychosocial Wellness will be assessed using the (anxiety: Memorial Anxiety Scale for PCa, MAX-PC; stress: Perceived Stress Scale, PSS). These questionnaires have been used in PCa survivors to examine the effectiveness of a high intensity interval training exercise intervention in improving psychosocial health (27). Both questionnaires have been validated in PCa survivors and have good internal consistencies (Cronbach's alpha >0.9) and test-retest reliability (ICC >0.85) (27,45).

Inflammatory Biomarker will be assessed using blood samples collected in a fasted state. Capillary blood samples will be collected using Tasso+ blood collection devices (Tasso inc., USA) on the upper brachium (40,62). Tasso devices suction to the arm or leg and perform a lancet prick to collect capillary blood. Blood samples will be centrifuged at 4°C for 15 minutes and plasma will be aliquoted and stored at -60°C until analysis (40). Plasma samples will be analyzed for C-reactive protein (CRP) concentrations at the Diabetes and Obesity Research Institute (DORI) core lab at USC.

Qualitative Analysis via Exit Interview

This analysis provides the participants' perspective on both aims. In this pilot study phase, it is meant to provide insights to why the feasibility outcomes and/or changes in efficacy measures may have occurred.

A semi-structured exit interview will be conducted at the end of the post-intervention data collection (T2). The interview will follow a script that asks about the participants' view on: 1) how the program affected their physical, cognitive, psychological, and social well-being; 2) their willingness to continue participating in similar types of programs and plans to continue golfing in the future; 3) barriers and facilitators to their participation in the program; and 4) if their expectations are met and would they be willing to recommend the program to their peers (Appendix 1). The interview will be approximately 20 minutes and will be recorded and transcribed. The recordings and transcripts will be analyzed using Braun and Clarke's six-phase approach (9). The process will begin with familiarization through verbatim transcription of the exit interviews, supported by note-taking and analytic memos to capture initial ideas and patterns (Phase 1).

Next, an inductive in vivo coding process will be used, utilizing the participants' own language to systematically identify and code meaningful segments of information as subgroups (Phase 2). These coded subgroups will then be examined and synthesized into broader patterns, or themes through an interpretive analysis (Phase 3). The themes will be rigorously reviewed to ensure internal coherence and authenticity to the original transcripts, with adjustments made as necessary (Phase 4). Each theme will be refined and clearly defined, accompanied by descriptive labels and supported by representative quotations from the transcripts (Phase 5). Finally, the refined themes will be presented in a coherent report, integrating relevant quotations and commentary linked to the interview content. For the write-up, a research associate will interpret the findings in relation to the research questions and relevant literature to ensure methodological transparency (Phase 6) (9,33). To minimize bias, the research associate conducting the thematic analysis will be different from the one conducting the interviews.

Statistical Analyses

The efficacy of the program will be assessed using a linear mixed-effects model (18,22,29,30). The models will examine changes in the 5 continuous dependent variables (FACT-P, SPPB, ICIQ-UI SF, MAX-PC, and PSS) with 3 timepoints (T0, T1, T2) as the fixed effects and the participant as the random effect (12,22,29). For each model, the fixed effects of time during the delay-entry control period (β_1) will be compared to the intervention period (β_2) for significance and magnitude (Figure 3). The intercept of the participant random effects (b_{0i}) will reveal how much the individual participant's baseline data deviates with the average baseline. The slope of participant random effects (b_{1i}) will reveal how much individual participant's change over time deviates from the average change over time. *Post-hoc* tests will be done on T0 - T1 and T1 - T2 timepoints to examine differences in the changes (12). Alpha level is set at 0.05. The different models will be compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), where the model with the lowest AIC and BIC will be considered the best fit (22).

$$\text{Outcome}_{ij} = \beta_0 + \beta_1 \times \text{Time1}_{ij} + \beta_2 \times \text{Time2}_{ij} + b_{0i} + b_{1i} \times \text{Time}_{ij} + \epsilon_{ij}$$

Where:

- i indexes the participant and j indexes the time point.
- β_0 is the overall intercept (mean outcome at baseline).
- β_1 and β_2 are the fixed effects of Time1 and Time2, respectively.
- b_{0i} and b_{1i} are the random intercept and slope for participant i, respectively.
- ϵ_{ij} is the residual error.

Figure 3. Equation for Linear Mixed Effects Model Used to Assess GREENS Program Efficacy.

DISCUSSION

The GREENS program is a novel activity intervention, designed to deliver multimodal exercise activities including golf play, body-weight and band-resistance exercises, and social support for PCa survivors. The present study examined the feasibility and efficacy of the program, which is essential prior to the design of a future randomized controlled trial.

Multimodal Recreational Activities (MRAs)

Traditional modalities of resistance and aerobic exercises are effective in improving anxiety, depressive symptoms, fatigue, physical function, and health-related quality of life, but may not appeal to cancer survivors (11,21,47). Moreover, the reported adherence rates for many of these traditional programs are between 49% and 94% for 12-week programs, demonstrating high variability (56). MRAs such as football, dragon boat racing, triathlons, wall climbing, and golf are multimodal and inherently include elements of fun, social support, cognitive challenges, and physical tasks (14,24,27,32). Also, they have been shown to improve QoL, physical function, body composition, and psychological well-being (14,17,32). Although adherence rates for 12 to 14-week football and dragon boat racing studies are similar to the studies with traditional modalities, football and dragon boat racing have demonstrated long-term adherence to programs ranging from 6 months up to 5 years (7,14,32,58-61). Notably, a 6-month football program achieved 59% attendance rate, and a dragon boat demonstrated 79% attendance rate (32,59,61).

When it comes to choosing an MRA, the participants are more likely to select activities based on personal preferences and intrinsic factors (e.g., enjoyment and motivation) (1,32,51,52,56) that provide the survivors of PCa safe and effective program options, which should be an important goal for exercise oncology professionals. The GREENS program is a golf-based

MRA that is designed based on prior programs that have been proven safe, feasible, adherent, and enjoyable in older-adult males and females, and in male veterans (17,27,34).

The current study addressed the lack of evidence regarding the use of a golf-based MRAs that address physical and psychosocial symptoms in exercise oncology and PCa survivorship care. The study provides essential evidence to clinicians when advising appropriate activity engagement according to the patient's physical and psychosocial status. It also provided insights to researchers designing future MRAs for cancer survivors.

Study Design

An overwhelming amount of data support that exercise improves physical and psychosocial health and overall QoL in PCa patients (11,12,32). Thus, in this small feasibility study, we chose a delayed-entry design, which is recommended by the ORBIT model for developing behavioral treatments for chronic diseases (16). The delayed-entry design provides a within-subject comparison between the changes in the control period and the intervention period, while allowing all the participants to experience the intervention. Furthermore, the mixture of quantitative and qualitative analyses was expected to yield important insights to the program's efficacy on the cohort and individual differences (14,30).

Study Significance

Demonstrating the safety, adherence, and feasibility of the GREENS program in PCa survivors is an important step in advancing cancer and survivorship care. Successfully validating the use of MRAs within PCa survivors addresses exercise and support group adherence issues and sets the stage for broader applications. The findings can inform the implementation of golf-based MRAs and other MRAs to boost physical activity and exercise engagement in the PCa survivor community, as well as other cancer survivor communities.

Given the promising outcomes of other recreational activity programs in enhancing physical health and overall well-being in cancer survivors, and the previous success of the golf-intervention program in older adults and military veterans, similar health benefits are anticipated in PCa survivors (17,27,32,34). Such benefits are likely to include enhanced physical and psychological health and wellness, and overall QoL. Moreover, a detailed assessment of the GREENS program's preliminary effects will be essential for future research. By evaluating the health impact of the program, the data can be used to estimate the intervention's true effectiveness. This information is vital for understanding the program's potential and for the design of a future adequately powered randomized control trial that could lead to evidence-based recommendations for integrating MRAs into standard survivorship care.

CONCLUSIONS

There is a need to optimize health, wellness, and QoL in post cancer diagnosis and treatment, especially in prostate cancer survivors. The present study tested the feasibility and efficacy of a multimodal recreational activity program, such as the proposed GREENS program. It addressed the current lack of evidence in using a golf-based multimodal recreational activity program to address physical and psychosocial symptoms in prostate cancer survivors. The results of the study will inform future clinical practice and intervention design.

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Appendix 1. Exit Questionnaire Script.

We would like to learn about your thoughts regarding participation in the Golf Recreational Exercise for Enhanced Survivorship in Prostate Cancer Survivors study. Please answer the following questions…

1. In your opinion, how has your involvement in the 10-week GRRENS study affected your
   a. physical function (for example: physical endurance, strength, flexibility, sleep, other)?
   b. cognitive function (for example: memory, concentration, attention, and other)?
   c. mental wellbeing (for example: stress, anxiety, and other)?
   d. social wellbeing (for example: support, friendship, trust)?
2. Would you recommend participation in this program to your friends? Why?
3. Would you change anything in the program to improve it?
4. Will you continue to play golf once the study is over? If so, where will you play?
5. Will you more likely to continue golfing/exercising if you this kind of program exists for longer periods of time?
6. What were the barriers that you encountered, that disrupted your participation in the program? For example, transportation, distance, treatment appointments, etc.
7. What were the facilitators that you encountered that increased your participation in the program? For example, group members, accountability to members of the program, free golf lessons, etc.

Acute Effects of D- and L-Beta-Hydroxybutyrate on Vigilance (Sustained Attention and Reaction Speed) in Healthy Adults: A Randomized, Double-Blind, Placebo-Controlled Trial

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ABSTRACT

Jiannine L, Holen C, Antonio J. This study evaluated whether a low dose, acute ingestion of beta-hydroxybutyrate (D-BHB) or L-BHB influences vigilance (i.e., sustained attention, reaction speed), fine motor control, memory, mood, or strength in fasted, non–keto-adapted healthy adults. A total of 136 participants (20.5 ± 1.4 years; 70.2 ± 15.6 kg) were randomized into 3 Groups: D-BHB (n = 47), L-BHB (n = 46), or placebo (n = 43). Measures included the Psychomotor Vigilance Test (PVT reaction time) and handgrip strength (mean and peak). Assessments were conducted at baseline and 60 minutes post-consumption. The data were analyzed using a two-way ANOVA with *post hoc* Tukey Tests where appropriate. An exploratory analysis was also conducted to assess within-group changes over time and to estimate effect sizes. A significant group effect was found for reaction time (P = 0.033). Group B (L-BHB) performed significantly faster than placebo (P = 0.029). No time or interaction effects we noted. Lapse counts were higher in the Placebo Group compared to both BHB Groups (P = 0.004). The ANOVA did not show a significant group × time interaction. The main study effect was that both BHB Groups (D- and L-) had fewer lapses overall compared to the Placebo Group, regardless of time point. In the absence of significant time effects (all P > .05), exploratory analyses were conducted to assess within-group changes over time and to estimate effect sizes. Although the ANOVA did not identify statistically significant effects, within-group paired *t*-tests and effect size, estimates were computed to explore potential patterns. These small effect sizes (Group A: 0.264; Group B: 0.271) suggest small changes within Group A and Group B between the pre- and post-60-minute time points. Significant Group differences were found for peak (P = 0.016) handgrip strength. *Post-hoc* tests revealed that Group A (D-BHB) significantly outperformed Group B (L-BHB), while Group C (the Placebo) did not differ from either. Also, an effect size calculation showed a small improvement in both Group A and Group B, with no change in Group C. Thus, the acute ingestion of BHB, particularly the L-isomer, shows a trend towards improved psychomotor attention and reaction time compared to the Placebo Group. Handgrip performance also differed by Group, with the D-BHB Group showing greater strength than the L-BHB Group. There were no significant differences observed on group x time effects. The findings indicate that acute BHB ingestion, particularly the L-BHB, improved reaction speed and reduced attentional lapses compared to the placebo, even at a low 2 g dose. While handgrip strength differed between BHB isomers, neither outperformed the placebo over time. Overall, the data suggests potential cognitive benefits of exogenous BHB on sustained attention at low doses, which supports the need for further dose-response and mechanistic research.

Key Words: Handgrip Strength, Ketone, Performance, Psychomotor Vigilance

INTRODUCTION

Beta-hydroxybutyrate (BHB), a primary ketone body produced during fasting, ketogenic diets, or supplementation acts as an alternative brain fuel and modulates neuroinflammation, synaptic plasticity, and neuroprotection. Most research demonstrates cognitive improvements in animal models of neurodegeneration, metabolic stress, or brain injury, with emerging but mixed evidence in humans (4-6,9,11).

Prior research has focused largely on endurance exercise or metabolic parameters, often in fasted or carbohydrate-restricted states (2,3). Few studies have directly compared the acute effects of BHB isomers on neurocognitive and neuromuscular function in a non-fasted, healthy population. Moreover, the physiological uptake and utilization of the D- and L-isomers are not well understood. D-BHB is the main form produced during fasting, ketogenic diets, and prolonged exercise; whereas, L-BHB is produced in much smaller amounts, is less favored for oxidation, but may have unique neuroprotective roles (1,10) as a signaling molecule.

This study investigates the acute effects of D-BHB and L-BHB supplementation, compared to placebo, on psychomotor vigilance and handgrip strength in healthy young adults. By incorporating both cognitive and neuromuscular indices and analyzing group- and time-dependent effects, the study aims to clarify whether exogenous BHB provides pragmatic benefits.

METHODS

Subjects

The study protocol and consent procedures complied with the Declaration of Helsinki. The participants were informed of their rights, the purpose, methods, risks, and benefits of the research, and they were told that their participation was voluntary and that they could withdraw at any time without reprisal. The protocol was approved by the university IRB (2025-304).

A randomized, double-blind, placebo-controlled design was used to assess the effects of acute BHB supplementation on indices of performance. Healthy men and women (N = 136; D-BHB: n = 47, L-BHB: n = 46, Placebo: n = 43) participated in this study. The participants were randomly assigned to receive a single 2 g dose of D-BHB, L-BHB, or a placebo. Baseline assessments included anthropometric measures, psychomotor vigilance (PVT), and handgrip strength. After baseline characteristics were assessed, the subjects consumed one of the 3 drinks provided (i.e., D-BHB, L-BHB, or placebo). At 60 minutes post-consumption, the following assessments were repeated.

- **Psychomotor Vigilance Test (PVT):** Participants completed a computerized test of sustained attention and alertness at baseline and 60 minutes post-supplementation. During the PVT, participants are instructed to respond as quickly as possible to a visual stimulus (i.e., a number) that appears on a screen at random intervals over a designated period, often five minutes. Each appearance of the stimulus is brief and unpredictable, and the primary data collected are the reaction times.

- **Handgrip Strength:** Peak handgrip strength was measured via a calibrated dynamometer at baseline and follow-ups. Each subject was standing, with the elbow at 90 degrees, and was instructed to squeeze the dynamometer maximally. They were allowed 3 attempts.

Statistical Analysis

The data were analyzed using Python (Statsmodels and SciPy libraries). A two-way ANOVA was conducted to evaluate the effects of Group (A, B, C; between-subjects factor) and Time (Pre, Post60; within-subjects factor) on psychomotor vigilance reaction time. Prior to analysis, the data were screened for normality using the Shapiro-Wilk Test and homogeneity of variance using the Levene's Test; all assumptions were met. The two-way ANOVA assessed the Main effect of Group, the Main effect of Time, and Group × Time interaction. In the absence of significant effects (all $P > .05$), exploratory analyses were conducted to assess within-group changes over time and to estimate effect sizes.

In this study, the Group × Time interaction tested whether changes from baseline to 60 minutes differed between the placebo Group, the D-BHB Group, and the L-BHB Group. A significant interaction would have indicated that one supplement produced a unique improvement over time compared to the others. Although no Group × Time interactions were found for attention, reaction time, or handgrip strength, the overall group differences showed meaningful patterns, such as faster reaction speed in the L-BHB Group and fewer lapses in both BHB Groups. Because these patterns did not appear in the interaction term, we conducted additional exploratory analyses that included within-group paired *t*-tests and effect size estimates to better understand the direction and magnitude of these changes. Paired *t*-tests were performed within each group to evaluate Pre vs. Post60 changes. Effect sizes (Cohen's *d*) were calculated for within-group (paired) and between-group (independent) comparisons to quantify the magnitude of differences, even in the absence of statistical significance. Descriptive trends were visualized using reaction time profiles across the Groups and timepoints to support interpretation of potential group-level patterns. All analyses used a significance level of $\alpha = 0.05$.

RESULTS

The participants' baseline characteristics showed no significant Group differences (see Table 1).

Table 1. Subject Characteristics.

	Group A D-BHB (n = 47)	Group B L-BHB (n = 46)	Group C Placebo (n = 43)
Age (yrs)	20.7 ± 2.0	20.5 ± 1.2	20.3 ± 1.0
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Weight (kg)	70.1 ± 15.3	69.8 ± 17.0	70.6 ± 14.3
BMI	24.5 ± 4.7	24.3 ± 3.6	23.8 ± 2.7

The data are expressed as the mean ± SD. Legend: **BMI** = Body Mass Index (weight/height^2), **kg** = Kilograms, **m** = Meters, yrs = Years. An unpaired *t*-test revealed no significant differences between the Groups. Group A (21 males and 25 females); Group B (24 males and 22 females); Group C (22 males and 22 females).

Psychomotor Vigilance (Attention and Reaction Time)

A two-way analysis of variance (ANOVA) was conducted to examine the effects of Group (A, B, and C) and Time (Pre vs. Post60) on psychomotor vigilance reaction time. The results revealed no significant main effect of Group, $F(2, 266) = 1.99$, $P = .138$, and no significant main effect of Time, $F(1, 266) = 0.94$, $P = .333$. Furthermore, the Group × Time interaction was not significant, $F(2, 266) = 0.44$, $P = .647$. Assumptions of normality and homogeneity of variance were met (i.e., the Shapiro-Wilk Test indicated no significant deviations from normality ($P > .05$), and the Levene's Test confirmed equal variances at both time points (Pre: $P = .22$; Post60: $P = .13$).

Exploratory Analysis: Within-Group Comparisons and Effect Sizes

Although the ANOVA did not identify statistically significant effects, within-group paired *t*-tests and effect size estimates were computed to explore potential patterns. These small effect sizes suggest minor changes within each Group between Pre and Post 60-min time points (Table 2 and Figure 1).

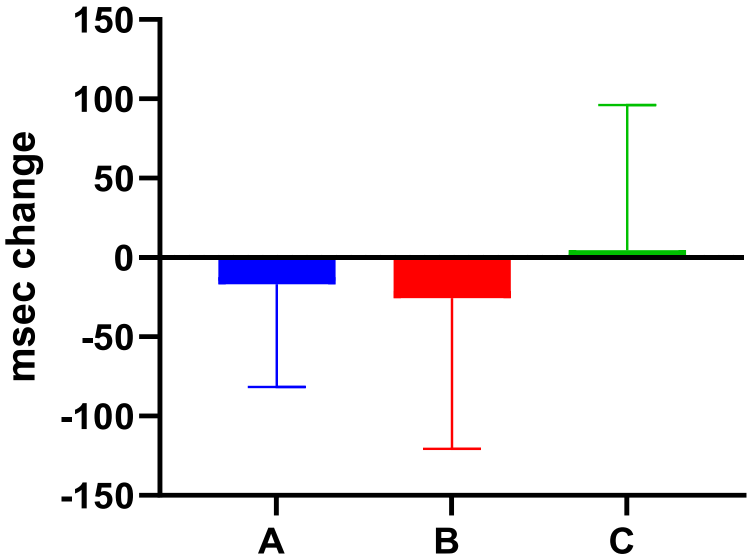
Table 2. Psychomotor Vigilance Test (PVT) – Reaction Time.

	Group A D-BHB (n = 47)	Group B L-BHB (n = 46)	Group C Placebo (n = 43)
RT Pre (msec)	412 ± 92	397 ± 138	415 ± 128
RT 60-min	395 ± 85	371 ± 7	419 ± 136
Cohen's d	-0.264	-0.271	0.051
P value	0.077	0.073	0.738

The data are expressed as the mean ± SD. Legend: **msec** = milliseconds.

TIME EFFECTS (Pre vs. Post60)

Figure 1. Psychomotor Vigilance (Attention and Reaction Time). The data are presented as the mean and standard deviation. Groups A and B improved similarly (d ≈ -0.27; small effect size); Group C showed no change.



	A	B	C
Mean	-17.00	-25.72	4.721
Std. Deviation	64.61	94.86	91.38
Std. Error of Mean	9.424	13.99	13.94

Table 3 shows that there were no effects of the treatment on handgrip strength.

Table 3. Peak Handgrip Strength.

	Group A D-BHB (n = 47)	Group B L-BHB (n = 46)	Group C Placebo (n = 43)
Pre	37 ± 10	41 ± 16	37 ± 14
60-min	38 ± 10	44 ± 17	40 ± 13
Delta	1 ± 5	3 ± 7	3 ± 7

The data are expressed as the mean ± SD. Legend: **msec** = milliseconds.

Although Group B showed significantly higher strength than Group A overall (P = 0.048), Group B did not reach significance in overall strength from Groups A and C. Also, there was no significant Time × Group interaction (P = 0.215) or an effect of Time (P = 0.229).

CONCLUSIONS

This study employed a challenging design for detecting nutritional effects of a single, low 2-gram acute dose administered to healthy, fasted, and non-keto-adapted adults, which is a population that measurable cognitive or performance shifts are typically difficult to detect. Exploratory within-group analyses reveal small but consistent improvements for both the D-BHB and the L-BHB Groups with no changes in the Placebo Group. Collectively, these results highlight that exogenous BHB, especially the L-isomer condition that may enhance aspects of attention and reaction performance under acute, low-dose conditions. Future research should examine longer treatment durations, higher dosages, and perhaps different populations.

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Effect of Mindful Thai Dance Intervention on Heart Rate Variability in Elderly Patients with Diabetic Kidney Disease

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ABSTRACT

Chunkum S, Susantitaphong P, Tanaka H, Suksom D. Effect of Mindful Thai Dance Intervention on Heart Rate Variability in Elderly Patients with Diabetic Kidney Disease. Type 2 diabetes mellitus (T2DM) is highly prevalent among the elderly and frequently leads to diabetic kidney disease (DKD), which is associated with autonomic nervous system dysfunction and increased cardiovascular risk. Heart rate variability (HRV) is a sensitive marker of autonomic regulation that is commonly impaired in DKD. Mind–body exercise has gained attention as a complementary intervention to improve autonomic function; however, evidence in elderly patients with DKD remains limited. This study aimed to investigate the effects of a 12-week mindful Thai dance program on HRV and anthropometric parameters in elderly patients with DKD. Thirty-six elderly patients with DKD were assigned to a mindful Thai dance group (MTD, n = 17) or a non-exercise control group (CON, n = 19) using a matched-pairs design based on age, sex, and disease severity. The MTD group participated in a 12-week program (50 min/session, 3 sessions/week) at 40–60% of heart rate reserve, while the CON group maintained their usual daily activities. HRV parameters, including low-frequency power (LF), high-frequency power (HF), LF/HF ratio and anthropometric were assessed at baseline and post-intervention. After 12 weeks, the MTD group demonstrated significant reductions in body weight and waist circumference compared with baseline ($P < 0.05$). In addition, HRV analysis demonstrated significant improvements in autonomic modulation, with reduced LF and LF/HF ratio and increased HF compared with both baseline and the CON group ($P < 0.05$). No significant changes were observed in the CON group. These findings indicate enhanced parasympathetic activity and improved autonomic balance following mindful Thai dance training. Mindful Thai dance may serve as a safe and effective complementary exercise modality for improving cardiovascular autonomic function in elderly patients with DKD.

Key Words: Autonomic Nervous System, Diabetes, Diabetic Kidney Disease, Mind-Body Interaction

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a major global public health problem, particularly among the elderly population. The prevalence of T2DM continues to increase with aging. One of the most serious microvascular complications is diabetic kidney disease (DKD), which is the leading cause of chronic kidney disease and end-stage renal failure worldwide (2,13). In addition to progressive renal impairment, patients with DKD are at markedly increased risk for cardiovascular morbidity and mortality due to autonomic dysfunction, hypertension, and vascular abnormalities (1,21). Cardiac autonomic neuropathy (CAN) is a common but often underdiagnosed complication in patients with diabetes and DKD. It is characterized by an imbalance between sympathetic and parasympathetic nervous system activity and is associated with arrhythmias, impaired blood pressure regulation, and sudden cardiac death (19,22). Heart rate variability (HRV) is a widely accepted noninvasive method for evaluating cardiac autonomic regulation. Reduced HRV, reflected by decreased high-frequency power (HF) and increased low-frequency power (LF) and LF/HF ratio, indicates sympathetic dominance and parasympathetic withdrawal, which are commonly observed in patients with diabetes and chronic kidney disease (14,17).

Regular physical activity is a cornerstone of non-pharmacological management for diabetes and its complications. Aerobic exercise and mind–body interventions have been shown to improve glycemic control, endothelial function, and autonomic balance (3,7). Mind–body exercises integrate physical movement with controlled breathing and focused attention, producing both physiological and psychological benefits. Previous studies in older adults and patients with chronic diseases demonstrate that mind–body exercise enhances parasympathetic activity, suppresses sympathetic overactivity, and improves HRV (10,12). Mindful Thai dance is a traditional rhythmic movement practice that integrates coordinated movements, flowing movements with focused attention and postural control. Its characteristics are comparable to other established mind–body exercises such as Tai Chi and Qigong, which are known to improve autonomic regulation, balance, and cardiovascular health (8,24,26). Mindful Thai dance is culturally appropriate, low-impact, and safe for elderly individuals with chronic diseases. However, despite its increasing clinical application, scientific evidence regarding its effects on cardiac autonomic function, particularly in elderly patients with DKD, remains limited.

Therefore, the purpose of this study was to investigate the effects of a 12-week mindful Thai dance intervention on heart rate variability in elderly patients with diabetic kidney disease compared with a non-exercising control group. We hypothesized that mindful Thai dance training would improve autonomic nervous system balance, as indicated by increased parasympathetic nervous system activity and reduced sympathetic dominance.

METHODS

Subjects

This randomized controlled trial enrolled 36 elderly patients with diabetic kidney disease (DKD), aged 60–75 years. Recruitment was conducted through outpatient clinic screening at Chulalongkorn Hospital, Bangkok, Thailand. Eligible participants were required to have type 2 DKD with HbA_{1c} levels between 7–9%, a normal resting electrocardiogram, no musculoskeletal limitations to exercise, and no participation in structured exercise programs within the previous 6 months. Eligibility was confirmed through medical record review and self-report.

All participants provided written informed consent prior to participation, and the study protocol was approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University. Participants were matched according to age, sex, and disease severity and then randomly allocated to either the mindful Thai dance (MTD; n = 17) or non-exercising control (CON; n = 19) group. During the intervention period, four participants (one from CON and three from MTD) withdrew due to health-related reasons and were excluded from the final analysis.

Procedures

Measurements were conducted in the exercise physiology laboratory. The participants were requested to abstain from alcohol consumption for 24 hours and caffeine for 12 hours before the tests. No vigorous exercise was performed for at least 24 hours before the testing.

Height, body weight and body mass index were determined using a bioelectrical impedance analyzer (ioi-353; Jawon Medical, Seoul, Korea). The MTD program consisted of 50-minute sessions, three times per week, for 12 weeks. Exercise intensity was prescribed at 40–50% of heart rate reserve (HRR) during Weeks 1–6 and 51–60% HRR during Weeks 7–12, calculated using the Karvonen formula. Perceived exertion was monitored via the Borg original RPE scale (target 10–11). Each session included a 10-minute warm-up and cool-down with stretching and relaxation. The core MTD program included nine traditional Thai dance postures performed in 8-count cycles, emphasizing coordinated movements of the arms, torso, and legs, combined with mindful attention to motion. Music rhythm ranged from 100–110 beats per minute. Participants practiced dynamic meditation by focusing on arm movements and counting aloud during each cycle. The CON group maintained usual lifestyle habits and continued standard medical care.

Heart rate variability (HRV) was assessed using a Polar H10 heart rate sensor (Polar Electro Oy, Kempele, Finland), which has been validated for accurate R–R interval recording. Participants were instructed to avoid caffeine, alcohol, and vigorous physical activity for at least 24 hours prior to testing. All measurements were conducted in a quiet, temperature-controlled laboratory. After a 10-minute seated rest to stabilize cardiovascular function, R–R intervals were recorded continuously for 5 minutes in a relaxed seated position with spontaneous breathing and minimal movement. The recorded R–R interval data were exported and analyzed using Kubios HRV Scientific software version 4.2.0 (University of Eastern Finland, Kuopio, Finland). Artifact correction was applied using the automatic correction algorithm with a moderate filter setting. Frequency-domain HRV indices, including low-frequency power (LF, 0.04–0.15 Hz), high-frequency power (HF, 0.15–0.40 Hz), and the LF/HF ratio, were calculated using fast Fourier transformation. These indices were used to assess autonomic nervous system modulation.

Statistical Analyses

Sample size was calculated using G*Power 3.1.9.2 for a repeated-measures ANOVA (within-between interaction), with $\alpha = 0.05$, power = 0.8, and effect size = 0.454, based on prior exercise studies in type 2 diabetes (Kang et al., 2016). Descriptive data are expressed as mean

± SD. Outliers (1–3 data points per variable) were identified using Grubbs' test and removed; exclusion did not alter primary outcomes. Normality was assessed with the Shapiro–Wilk test. Primary analyses were conducted using a 2×2 (group × time) repeated-measures ANOVA, with post hoc LSD multiple comparisons. For variables violating normality assumptions, the Friedman test was used to evaluate within-group changes over time, and Mann–Whitney U test was applied for between-group comparisons. In this case, data are expressed as median (interquartile range, IQR). Statistical significance was set at $P < 0.05$ for all comparisons. All analyses were performed using SPSS version 23 (IBM, Armonk, NY).

RESULTS

The general characteristics of the participants are shown Table 1. Significant reductions in body weight and waist circumference were observed only in the MTD group ($P < 0.05$), while no significant changes were found in the CON group.

Table1. General Participant Characteristics Before and After 12 Weeks of Non-Exercising Control and Mindful Thai Dancing Interventions in Elderly Patients with Diabetic Kidney Disease.

Variables	Control (n = 19)		Dancing (n = 17)		ANOVA		
	Pre	Post	Pre	Post	Time	Group	Inter-action
Male/Female (n)	7/12		3/14				
Age (yr)	68.2 ± 4.3		69.4 ± 4.7				
Height (cm)	157 ± 6		155 ± 6				
Body Weight (kg)	62.9 ± 10.4	62.7 ± 9.6	61.8 ± 10.8	59.6 ± 10.6*	0.001	0.543	0.003
Body Mass Index ($kg{\cdot}m^2$)	25.0 ± 3.8	25.2 ± 3.6	25.4 ± 3.0	24.3 ± 2.6	0.539	0.258	0.087
Waist Circumference (cm)	88.7 ± 7.5	88.7 ± 7.0	86.3 ± 12.4	81.8 ± 11.3*	0.010	0.165	0.010

Values are means ± SD. *$P<0.05$ vs. Pre.

Table 2 presents heart rate variability before and after the 12-week intervention. In the CON group, LF significantly increased while HF decreased, resulting in a significant rise in the LF/HF ratio ($P < 0.05$). In contrast, the MTD group exhibited a significant reduction in LF and a significant increase in HF, accompanied by a marked decrease in the LF/HF ratio ($P < 0.01$).

Between-group comparisons showed significant differences in LF, HF, and LF/HF ratio (all P < 0.01).

Table 2. Heart Rate Variability (HRV) Before and After 12 Weeks of Non-Exercising Control and Mindful Thai Dancing Interventions in Elderly Patients with Diabetic Kidney Disease.

Variables	Control (n = 19)		Dancing (n = 17)			
	Pre	Post	Pre	Post	χ^2 (df)	P-value
Low Frequency (ms^2)	78.4 (73.5-89.0)	101.3 (82.7-121.6)*	74.0 (61.9-83.8)	44.5 (38.1-69.4)*†	17.9 (3)	<0.001
High Frequency (ms^2)	70.0 (41.0-103.4)	65.3 (33.9-75.6)*	83.5 (55.4-134.4)	108.0 (91.8-188.5)*†	9.9 (3)	0.019
LF/HF ratio	1.0 (0.4-1.2)	1.6 (1.4-2.2)*	1.3 (0.8-1.7)	0.4 (0.3-0.5)*†	24.5 (3)	<0.001

Values are median (IQR). **LF** = Low Frequency, **HF** = High Frequency. *P<0.05 vs. Pre, † P<0.05 vs. Control.

DISCUSSION

The present study demonstrates that a 12-week mindful Thai dance (MTD) intervention significantly improved autonomic nervous system function in elderly patients with diabetic kidney disease (DKD). Notably, the MTD group exhibited marked improvements in heart rate variability (HRV), while no favorable changes were observed in the control group.

A major finding of the present study was the significant improvement in heart rate variability (HRV) following mindful Thai dance (MTD) training. The MTD group demonstrated a significant reduction in low-frequency (LF) power and the LF/HF ratio, along with a significant increase in high-frequency (HF) power, indicating enhanced parasympathetic modulation and improved sympathovagal balance. In contrast, the control group exhibited an unfavorable autonomic pattern, characterized by increased LF and LF/HF ratio and decreased HF. Impaired HRV is a common manifestation of diabetic kidney disease (DKD) and is strongly associated with increased cardiovascular morbidity and mortality (15,22). Sympathetic overactivity and reduced vagal tone play key roles in the development of hypertension, vascular dysfunction, and progressive renal injury (5). Therefore, the observed improvement in HRV following MTD training suggests a clinically meaningful enhancement in autonomic regulation mediated by the combined effects of rhythmic aerobic activity and focused meditative engagement.

The nine traditional Thai dance postures, performed continuously in 8-count cycles at a moderate rhythm (100–110 beats·min^{-1}), provide sustained submaximal aerobic stimulation that enhances vagal tone, lowers resting heart rate (4,11). In addition, the integration of mindful attention through synchronized movement awareness, and rhythmic counting elicits a relaxation response that suppresses hypothalamic–pituitary–adrenal (HPA) axis activity and attenuates sympathetic outflow (20). This neurophysiological response has been shown to reduce circulating stress hormones, enhance cardiac vagal modulation, and stabilize autonomic balance (16,20). Furthermore, the repetitive, coordinated whole-body movements increase peripheral shear stress, stimulating endothelial nitric oxide (NO) production and improving vascular function, which further supports autonomic cardiovascular regulation (5,7). Collectively, these mechanisms provide a physiological explanation for the significant improvement in HRV observed following MTD training. The present findings are consistent with previous studies on mind–body exercise modalities. Tai Chi and yoga interventions have similarly been shown to increase HF power and reduce the LF/HF ratio in older adults and in patients with metabolic and cardiovascular disorders (16,20), supporting the role of integrative movement-based meditation in autonomic rehabilitation.

CONCLUSIONS

The 12 weeks of mindful Thai dance training significantly improved cardiac autonomic regulation in elderly patients with diabetic kidney disease. The intervention led to improvements in heart rate variability, including a significant increase in parasympathetic activity (HF) and a reduction in sympathetic dominance (LF and LF/HF ratio), indicating improved autonomic nervous system balance. In contrast, no favorable changes were observed in the control group. These findings suggest that mindful Thai dance is an effective complementary exercise intervention for enhancing cardiovascular autonomic function in this high-risk population.

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Development of a Play-Based Program Using an Active Play Approach and Video Media to Promote Physical Literacy in Sixth-Grade Students

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ABSTRACT

Kupongpan P, Yiammit C, Khowsroy K. This study developed a play-based program integrating active play with video media to promote physical literacy among late elementary students, using a quasi-experimental single-group repeated measures design. Participants were 34 sixth-grade students, with an added 20% buffer for potential data loss. The research instruments included: (a) a play-based program based on the active play approach; (b) interactive activity videos accessed via QR codes; and (c) reliable physical literacy assessments. Data were analyzed using descriptive statistics and repeated measures ANOVA to compare physical literacy scores at pre-intervention, Week 4, and Week 8. Significant differences were analyzed by pairwise comparisons using the Bonferroni method with statistical significance set at .05. Results showed significant improvements in physical literacy across all time points. The integration of QR codes and video media with interactive elements enhanced intrinsic motivation, increasing engagement in physical learning. This study demonstrates the effective use of digital technology in physical education to design curricula that promote healthy behaviors in school-aged children. It also offers a new format for providing access to supplementary learning resources and encourages continuous experiential learning inside and outside the classroom. The findings also highlight the potential for using technology to enhance physical activity and support positive health behavior changes among youth in the digital age.

Key Words: Active Pay Media, Late Elementary Students, Physical Literacy Development, Play-Based Program

INTRODUCTION

This Play is a crucial mechanism for intellectual and social development, particularly for children aged 7-11 years, when they develop logical thinking skills. Starting at age 12, children begin to think abstractly and analyze more complex concepts (3).

The development of a physical activity promotion model based on physical literacy emphasizes building children's fundamental movement skills, such as balance, coordination, locomotion, and controlled body movement, to enhance confidence and promote physical activity (30). Children who develop physical literacy are better able to associate exercise with good health, and they also gain important social skills that include cooperation, sharing, and respect for others (14). These components are closely linked to physical activity through social, emotional, and environmental learning processes (8). Active play, especially outdoor play involving large muscle groups, supports these outcomes by promoting enjoyment, energy use, and fundamental skill development, while also fostering physical, emotional, and social growth (27,33). Active play includes three key elements: (a) providing environments that encourage movement and curiosity; (b) developing confidence and motor skill proficiency; and (c) supporting physical growth alongside academic learning (33). Furthermore, active play contributes to development across three domains (12): cognitive (thinking and understanding), affective (emotions, motivation, and social behavior), and psychomotor (movement skills and physical capability). It motivates children to participate in varied movement experiences, promotes creativity and problem-solving, and helps build resilience when facing challenges (4,15).

In addition, using digital media that combines text, images, and video can enhance learning effectiveness. According to Cognitive Load Theory (CLT) (26), the brain has limits in processing information. Thus, well-designed learning media can reduce cognitive load and improve learning efficiency (28).

Previous studies highlight the importance of exercise in children's development, as it enhances concentration, memory, and academic performance (10). Therefore, providing opportunities for play and physical activity is essential for balanced social and emotional growth (4). In promoting physical literacy, it is important to consider learning objectives, appropriate methods, and effective media (19). For instance, video media can support learning through visual demonstration, improving understanding (24), while digital tools such as QR codes can increase convenience and accessibility, especially for activities that develop physical skills (1).

Therefore, active play, video media, and physical literacy are interconnected. Video media provides students with clear knowledge and demonstrations of proper movement, while active play allows them to apply and practice these skills in real situations. Together, they enhance physical literacy by improving movement ability, motivation, and understanding of physical health, leading to increased and sustained physical activity.

For these reasons, this research aimed to design and develop a suitable exercise program for sixth-grade students and to evaluate its effectiveness and satisfaction. The goal was to enhance physical fitness in Thai children and provide teachers and relevant agencies with a practical framework for continuously promoting students' physical and mental health.

METHODS
Subjects

2.1 Design

A quasi-experimental design with a single-group pretest-post-test time series design was employed (9,29). with one sample group and repeated measures to track the results at Week 4 and Week 8.

2.2 Participants

The participants were 34 sixth-grade students from Anuban Chanthaburi School (Academic Year 1/2024). The sample size was determined using G*Power 3.1 with a one-way repeated measures ANOVA, assuming an effect size of 0.25, $\alpha = .05$, power = .80, and three measurement points, yielding a required sample of 28. To account for potential data loss, an additional 20% was included, resulting in a final sample of 34 students.

The ***Inclusion Criteria*** were: (a) informed consent from students and guardians, with the right to withdraw at any time; (b) sixth-grade students willing to participate and interested in improving physical skills or health; and (c) ability to safely perform physical activities without medical conditions that would limit participation.

2.3 Instruments

The experimental instrument was a play-based program using the active play approach and video media to promote physical literacy in sixth-grade students. The program was developed in four steps.

Step 1: Research – A literature review was conducted on active play, online learning, program development, and physical literacy.

Step 2: Key Point Analysis – Insights from the review were used to design the program, including (a) principles and objectives, (b) activity content, (c) assessment structure, and (d) instructional videos.

Step 3: Program Development – The program and supporting video media were created, and QR codes were generated for online access.

Step 4: Validation – Ten experts evaluated the program's content validity using a 4-level rubric (1 = no consistency to 4 = consistent). A content validity index of ≥ .80 was required for acceptance.

QR codes were generated to enable online access and dissemination. The program's content validity was evaluated by 10 experts using a 4-level holistic rubric (2) with an acceptable content validity index set at ≥ 0.80.

Data collection instruments included the following:

1. Two Theoretical Physical Literacy Tests.

(1) Cognitive Domain (16 items, 16 points). It assessed knowledge and understanding across 4 areas: physical health (Items 1–4), physical competence (Items 5–8), physical activities (Items 9–12), and safety in physical activities (Items 13–16). Items were multiple-choice (A–D).

(2) Affective domain (12 items, 32 points): It assessed motivation and confidence in three areas: activity preferences (Items 17–20), enjoyment (Items 21–24), and perceived ability (Items 25–28). Responses were scored A = 4, B = 3, C = 2, D = 1.

2. Practical Physical Literacy Test.

Movement skills were evaluated using a four-level rubric: 4 = excellent, 3 = good, 2 = fair, 1 = low performance. The tests were piloted with 20 non-participating sixth-grade students to assess reliability using test–retest correlations, which showed statistically significant positive correlations at the .05 level. Reliability coefficients were high across components, and content validity indices were acceptable (I-CVI = 0.97, S-CVI = 0.83), with IOC ≥ 0.50 considered acceptable (20). Satisfaction was measured using a 5-point Likert scale (lowest to highest) (23).

2.4 Procedure

This research was conducted in accordance with ethical principles of consent, confidentiality, and participant anonymity. It was carried out in two phases:

Phase 1: Program Development.

Key concepts from the literature review were synthesized to design the program structure, integrate video media, and create distribution channels. The alignment between key concepts and program activities was evaluated by experts.

Phase 2: Program Implementation and Evaluation.

Step 1: Preparation – Permission and scheduling were coordinated with the school administrator.

Step 2: Implementation and Data Collection – A single-group repeated measures quasi-experimental design was used, with assessments conducted at pre-intervention, Week 4, and Week 8.

Step 3: Data Analysis – Descriptive statistics (mean, standard deviation, frequency, and percentage) were used to summarize physical literacy and satisfaction scores. Repeated measures ANOVA tested differences across the three time points. When significant differences occurred ($P < .05$), Bonferroni-adjusted pairwise comparisons were performed. Statistical significance was set at the .05 level.

Step 4: Conclusion and Discussion – Findings were interpreted in relation to the research objectives, with consideration of implications and limitations.

2.5 Data Analysis

The data were analyzed using descriptive statistics to calculate the mean and standard deviation of physical literacy and satisfaction scores. Satisfaction levels were interpreted as follows: 1.00–1.80 = lowest; 1.81–2.60 = low; 2.61–3.40 = moderate; 3.41–4.20 = high; and 4.21–5.00 = highest. Physical literacy levels were analyzed using frequency and percentage at pre-intervention, Week 4, and Week 8.

Inferential statistics were used to compare mean physical literacy scores across the three time points. A repeated measures ANOVA was conducted (16,32). and when significant differences were found ($P < .05$), Bonferroni-adjusted pairwise comparisons were performed. Statistical significance was set at .05.

RESULTS

The 3.1 Learning media to promote physical literacy. The learning media to promote physical literacy consisted of the activities designed to provide knowledge about physical literacy, physical health, physical fitness, physical activities, sports, exercise, and injury prevention during play.

Figure 1. QR-Code for the Learning Media to Promote Physical Literacy.

The participants were instructed to engage with and practice these activities for 15 minutes per day before starting the play activities based on the active play approach.

3.2 Development of movement skills and enhancement of physical literacy through the play-based program using the active play approach. The activities to enhance physical literacy were provided through the practice of 8 movement skills, 3 activities per skill, totaling 24 activities as follows:

Activity 1: Run Fast, Run with Heart. This activity develops forward running skills through three video-based active play tasks:

1) Tennis Ball Collection Run: Students run 10 meters to collect five tennis balls, moving back and forth on a speed ladder.

2) What's Correct and Fast: Students run 10 meters to a number grid displayed on a wall (0 to 9) and touch the correct answer to a given math question.

3) XO for Fun: In teams, students race 10 meters to place colored markers on a 9-square grid to play an XO game, running back and forth until one team wins.

Activity 2: Jump for Fun, Maintain Balance. This activity develops stationary jumping skills through three video-based active play tasks:

1) Double-Leg Hopping: Students hop forward and backward along a 10-meter marked path using both feet

2) One-Leg Hopping: Students hop forward and backward along the same path using one leg.

3) Relay Jumping: In two teams, students take turns hopping (one-leg and two-leg) along a 10-meter course, passing a cloth to the next teammate until all have completed the sequence.

Activity 3: Throw–Catch to Build Relationships. This activity develops tennis ball receiving skills through three video-based active play tasks:

1) One-Ball Throw and Catch: Students throw and catch one tennis ball vertically using one hand.

2) Two-Ball Throw and Catch: Students throw and catch two tennis balls vertically using one hand.

3) Alternate Throw and Catch: Students hold a ball in each hand and throw and catch them alternately using both hands.

Activity 4: Throw Accurately to Reach the Moon. This activity develops one-handed overhead throwing skills through three video-based active play tasks:

1) Basket Throw: Students throw two tennis balls into a basket placed 5 meters away, then rotate to the end of the line.

2) Bottle Knockdown: Students throw two tennis balls at a water bottle target positioned 10 meters away to knock it over.

3) Wall Throw: In teams, students throw tennis balls against a wall, aiming for them to land in a basket placed near the wall from a 10-meter distance.

Activity 5: Fast Feet Challenge. This activity develops alternating foot-stepping skills through three video-based active play tasks:

1) Forward: Students alternate their steps in the Forward In and Out position.

2) Backward: Students alternate their steps in the Backward In and Out position.

3) Lateral: Students alternate their steps in the Lateral In and Out position.

Activity 6: Tiptoe Jumping, Better Than a Kangaroo. This activity develops tiptoe jumping skills through three video-based tasks:

1) Odd and Even Jumps: Students jump into numbered boxes; landing on an odd number requires jumping two boxes ahead, and landing on an even number requires jumping one box ahead.

2) Fun Spin: One student swings a rubber-ring rope in a circle while the others jump over it continuously.

3) Dice Points: Students take turns rolling a dice; everyone jumps according to the number rolled, landing only in designated circles.

Activity 7: Perfect Balance, No Falling. This activity enhances football dribbling skills through three video-based tasks:

1) Straight Dribble: Students dribble a football straight for 10 meters and back.

2) Zigzag Dribble: Students dribble through cones in a zigzag path for 10 meters and back.

3) Circle Dribble: Students spread out in an area, and the student last in alphabetical order begins dribbling around classmates to pass the ball to the next student, continuing until all have participated.

Activity 8: Kick Win. This activity develops football kicking skills through three video-based tasks:

1) Direct Pass: Students work in pairs to pass the ball using the inside of the foot over a 10-meter distance.

2) Bomb: Students kick the ball to knock down target cones from 10 meters away.

3) Unity: Students form two-person teams and compete in a target-kicking game. Teams play in a round-robin format, with winners advancing until one team remains.

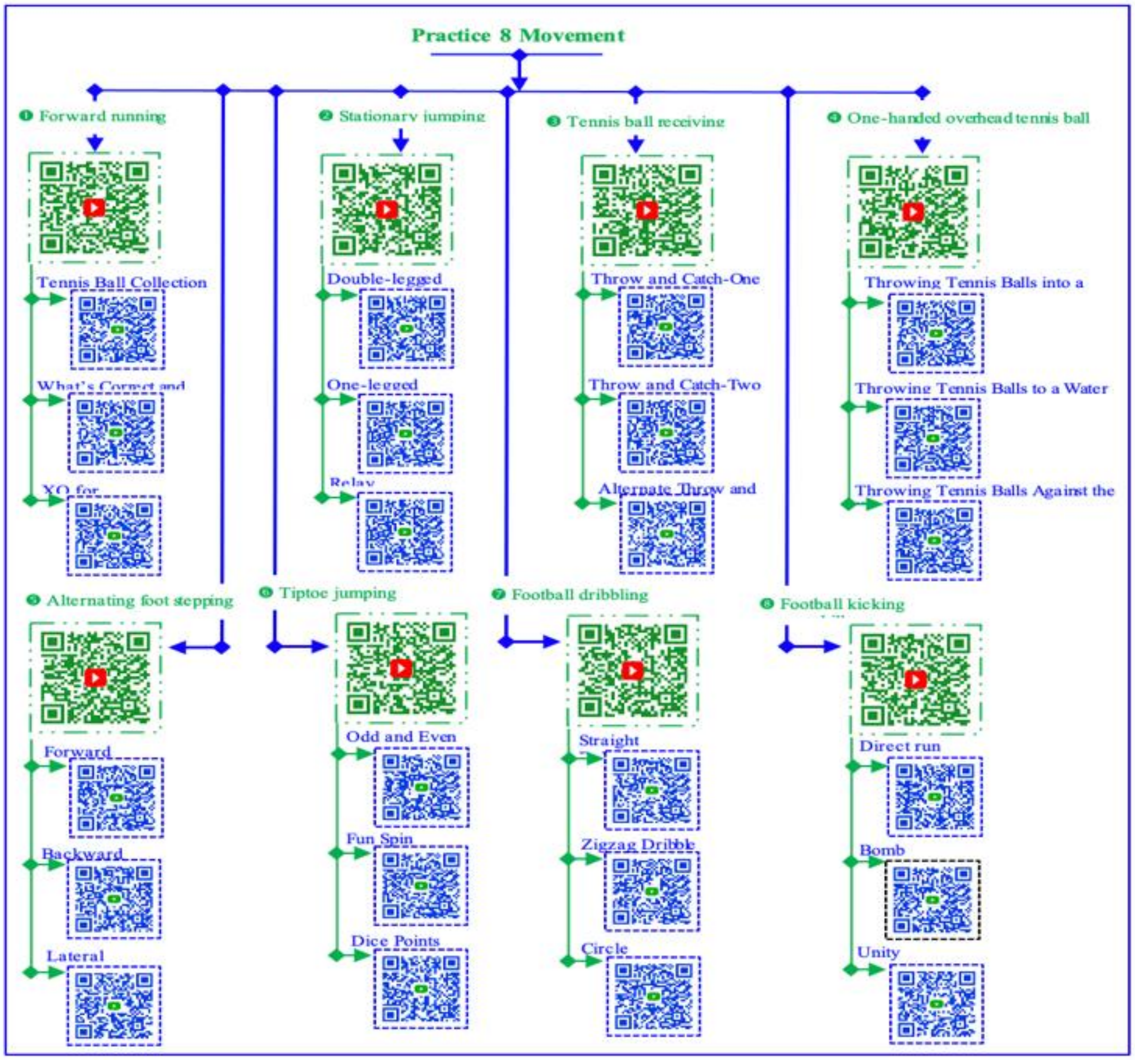

Figure 2. QR-Codes for Practice of 8 Movement Skills.

Note: Practice for 60 minutes a day, 3 days a week, over a total of 8 weeks, incorporating 8 activities and 24 active play sessions.

3.3 Effectiveness and satisfaction with the development of the play-based program using the active play approach.

The overall physical literacy levels of the sixth-grade students were assessed before and after the intervention. Prior to the intervention, 7 students (20.59%) exhibited low physical literacy; 9 students (26.47%) were at a fair level, 16 students (47.06%) showed a good level, and 2 students (5.88%) demonstrated excellent physical literacy. After Week 4 of the intervention, 1 student (2.95%) had low physical literacy, 11 students (32.35%) were at a fair level, 11 students (32.35%) were at a good level, and 11 students (32.35%) demonstrated excellent physical literacy. After Week 8, 4 students (11.77%) were at a fair level, 12 students (35.29%) were at a good level, and 18 students (52.94%) achieved an excellent level (Table 1).

Table 1. The Physical Literacy Levels of the Sixth-Grade Students.

Lists	Low		Fair		Good		Excellent	
	f	%	f	%	f	%	f	%
Pre-Intervention	7	20.59	9	26.47	16	47.06	2	5.88
After Week 4 of the Intervention	1	2.95	11	32.35	11	32.35	11	32.35
After Week 8 of the Intervention	0	0.00	4	11.77	12	35.29	18	52.94

Overall satisfaction with the play-based program at Week 8 was at the highest level (Mean = 4.69, SD = 0.31). The highest-rated areas were enjoyment and willingness to participate again in the active play activities (Mean = 4.88, SD = 0.33), learning about physical health through online media, and participation in Week 2 ("Jump for Fun, Maintain Balance") and Week 3 ("Throw-Catch to Build Relationships") activities (Mean = 4.82, SD = 0.39) (Table 2).

Table 2. Satisfaction with the Play-Based Program Using Active Play Approach and Video Media to Promote Physical Literacy of the Sixth-Grade Students.

Lists	M	S.D.
Acquiring knowledge and understanding of movement skills	4.29	0.46
Developing the ability to practice fundamental movement skills	4.21	0.64
Enjoying and wanting to participate in play activities using the active play approach	4.88	0.33
Feeling confident to express themselves and engage in active play activities with classmates	4.79	0.41
Learning about physical health through online media and activities		
Week 1: Active play "Run Fast, Run with Heart"	4.71	0.46
Week 2: Active play "Jump for Fun, Maintain Balance"	4.82	0.39
Week 3: Active play "Throw-Catch to Build Relationships"	4.82	0.39
Week 4: Active play "Throw Accurately to Reach the Moon"	4.71	0.46
Week 5: Active play "Fast Feet Challenge"	4.79	0.41
Week 6: Active play "Tiptoe Jumping, Better Than a Kangaroo"	4.71	0.46

Week 7: Active play “Perfect Balance, No Falling”	4.79	0.41
Week 8: Active play “Kick Win”	4.79	0.41
Total	4.69	0.31

Note: Assessment of satisfaction levels after Week 8 of the intervention.

3.4 Achievement in promoting physical literacy through the development of the play-based program using the active play approach.

The physical literacy in the cognitive domain, including knowledge and understanding, motivation, confidence, movement skills, and overall physical literacy, showed significant improvements from pre-intervention to Week 4 and Week 8 (P < .05) (Table 3).

Table 3. Physical Literacy of the Sixth-Grade Students.

Domains	Sources of variance	SS	df	MS	F	p
(Cognitive domain) knowledge, understanding	During the testing period	8.88	2.00	4.44	26.37	0.00*
	Error	11.12	66.00	0.17		
Motivation	During the testing period	526.02	2.00	263.01	93.67	0.00*
	Error	185.31	66.00	2.81		
Confidence	During the testing period	85.31	2.00	42.66	156.24	0.00*
	Error	18.02	66.00	0.27		
Movement skills	During the testing period	708.78	2.00	354.39	254.56	0.00*
	Error	91.88	66.00	1.39		
Overall physical literacy	During the testing period	8.01	2.00	4.00	170.63	0.00*
	Error	1.55	66.00	0.02		

* P < .05

Pairwise comparisons using the Bonferroni method showed significant differences in physical literacy across all three time points in the cognitive domain (knowledge and understanding), motivation, and confidence. Additionally, movement skills at Week 8 were significantly higher than both pre-intervention and Week 4 levels (P < .05) (Table 4).

Table 4. Differences of Physical Literacy of the Sixth-Grade Students.

Domain		Experiment		
		Before	Week 4	Week 8
Cognitive Domain (Knowledge, Understanding)		10.38	10.94	11.06
Before	10.38	-	-0.55*	-0.67*
After (Week 4)	10.94	-	-	-0.11*
After (Week 8)	11.06	-	-	-
Motivation		22.35	26.41	27.68
Before	22.35	-	-4.05*	-5.32*
After (Week 4)	26.41	-	-	-1.26*
After (Week 8)	27.68	-	-	-
Confidence		10.48	10.74	12.53
Before	10.48	-	-0.26*	-2.05*
After (Week 4)	10.74	-	-	-1.79*
After (Week 8)	12.53	-	-	-
Movement Skills		20.47	20.71	26.18
Before	20.47	-	-0.23	-5.70*
After (Week 4)	20.71	-	-	-5.41*
After (Week 8)	26.18	-	-	-

*P < .05

DISCUSSION

The play-based program using video media and QR codes effectively promoted physical literacy among sixth-grade students. The program was developed based on established program development principles, with clear objectives, student participation, cooperation, and systematic implementation. This aligns with the idea that well-structured and planned programs enhance learning effectiveness (21). The flexible weekly format and emphasis on hands-on participation are consistent with experiential learning theory (22), which stresses learning through active experience rather than passive instruction. Additionally, the program reflects active learning principles (5), encouraging engagement and skill development through meaningful activities. Its development and refinement also followed the ADDIE model (17), ensuring continuous improvement through analysis, design, development, implementation, and evaluation. The integration of QR codes and video media further enhanced learning, supporting the value of multimedia in deepening understanding (25). Overall, the program combined clear structure, active participation, technology integration, and ongoing evaluation, enabling it to effectively meet learners' needs and promote physical literacy.

The physical literacy of the sixth-grade students improved after participating in the play-based program. Before the intervention, overall physical literacy was at a fair level, with the cognitive domain (knowledge and understanding) at a good level, the affective domain (confidence and motivation) at a fair level, and movement skills at a low level. After Week 4, overall physical literacy increased to a good level, and by Week 8, continued improvement was observed. Specifically, the cognitive domain (knowledge and understanding) reached an excellent level, while both the affective domain (confidence and motivation) and movement skills developed to a good level. These results indicate that the program can effectively support student development.

This aligns with experiential learning theory (22), which emphasizes learning through active experience as more effective than passive instruction. Kolb stated that allowing learners to engage in practice stimulates the development of knowledge, understanding, and skills more effectively than learning through theory alone. It also supports self-determination theory (SDT) (13), which highlights the role of confidence and intrinsic motivation in promoting ongoing participation and physical development. However, comparison between Week 4 and Week 8 showed that while the cognitive domain continued to improve, movement skills still required more time for full development, consistent with the view that movement skills are behaviors that necessitate continuous practice and the accumulation of experience to reach expertise (18). Overall, the play-based program can effectively enhance knowledge, motivation, and confidence, while demonstrating steady improvement in movement skills, confirming its effectiveness in promoting physical literacy among elementary school students.

The overall physical literacy of the students showed significant improvement before the intervention and after Week 4 and Week 8, across all three dimensions: the cognitive domain (knowledge and understanding), the affective domain (motivation and confidence), and the psychomotor domain (movement skills). Paired comparison results indicated positive development in every domain, with the most notable improvement observed in the psychomotor domain by Week 8. This finding is consistent with (7), indicating that continuous practice and engaging activities effectively enhance movement skills.

Moreover, the increase in motivation and confidence in the affective domain aligns with self-determination theory (SDT) (13), which emphasizes that fostering a sense of interest, enjoyment, and perceived success supports sustained participation. The integration of video media and QR codes in the program further contributed to effective development by providing accessible learning resources that supported knowledge acquisition, motivation, and movement skill practice. These results confirm the program's potential to promote comprehensive and sustainable physical literacy development among elementary school students.

However, while the program demonstrated effectiveness, it is important to acknowledge its limitations, outline future research directions, and discuss practical implications.

Limitations

1) Program Design: As the game-based program developed is still in its initial phase, it is key to adapt the content and difficulty level of the activities to accommodate students with different physical abilities.

2) Technology and Accessibility: Although QR codes and videos are widely accessible, they require digital devices such as smartphones or tablets, which may not be available in all schools. In addition, the quality of video content may vary depending on the device used, and internet connectivity issues may affect learning effectiveness.

3) Evaluation: The absence of a control group makes it difficult to determine whether observed improvements are directly attributable to the program or influenced by external factors. Furthermore, relying solely on questionnaires and physical development tests may not fully capture changes in the students' attitudes or behaviors.

Future Directions

1) Program Refinement: Future iterations of the program should focus on flexibility and adjustable difficulty levels to better meet the needs of students with diverse physical abilities.

2) Digital Integration: Investigating the feasibility of incorporating an application or online platform to support active play activities could enhance student engagement and extend learning opportunities beyond the classroom.

3) Long-Term Tracking: Future research should aim to establish reliable indicators for tracking and monitoring students' physical development and behavior changes over time, especially after program completion.

Practical Implications

1) Movement Skill Development: Physical literacy learning supports the improvement of students' movement skills and body coordination.

2) Curriculum Integration: The play-based program can be adapted into school curricula to encourage active learning and integrate digital media within primary education.

3) Student Health and Behavior: The program may help reduce sedentary behavior, promote enjoyment in learning, build self-confidence, and encourage physical activity both in school and at home.

4) Educational Technology Application: The program can serve as a model for developing physical activity applications or digital platforms that support long-term positive behavioral change.

CONCLUSIONS

The play-based program using video media and QR codes was developed to enhance sixth-grade students' physical literacy through active participation and collaboration. Based on experiential and active learning principles, it encouraged hands-on practice, critical thinking, and teamwork. Over 4–8 weeks, students showed significant improvements in knowledge, motivation, confidence, and movement skills. The video-supported activities increased interest and engagement, aligning with play-based learning that supports both physical and cognitive development. Activities such as “Jump for Fun, Maintain Balance” and “Throw-Catch to Build Relationships” were especially well-received. Overall, the program effectively improved physical literacy and generated high satisfaction.

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A Combined Self-Efficacy and Resistance Training Model for Enhancing Psychological and Metabolic Health in Overweight Older Adults

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ABSTRACT

Kanlayawut O, Kritpet T. A Combined Self-Efficacy and Resistance Training Model for Enhancing Psychological and Metabolic Health in Overweight Older Adults. The purpose of this study was to examined the combined effects of resistance training and self-efficacy–based strategies on psychological outcomes and metabolic indicators in overweight older adults. Twenty-nine adults aged 60–75 years were randomly assigned to a Resistance Training Group (RT) or a Resistance Training with Self-efficacy Group (RTS). Both Groups completed a 12-week multi-joint resistance training program, while the RTS Group also received strategies based on Bandura's four sources of self-efficacy. Outcomes included self-efficacy (knowledge, capability, expected outcomes), fasting glucose, HDL-c, and hs-CRP. Analyses included percent change, correlations, and multiple regression. The RTS Group showed significantly greater improvements in knowledge (74.92% vs. 23.20%, P = 0.019) and self-efficacy capability (41.62% vs. 28.37%, P = 0.048). Expected outcomes improved in both Groups. Fasting glucose remained stable in the RTS Group (0.86% increase), but increased significantly in the RT Group (8.15%, P = 0.014). HDL-c and hs-CRP did not differ between Groups, though both were strongly correlated with self-efficacy outcomes. Regression analyses identified fasting glucose as the strongest metabolic predictor of knowledge and expected outcomes. In conclusion, integrating self-efficacy strategies into resistance training enhances psychological readiness and supports better glycemic regulation in overweight older adults. Favorable metabolic profiles were strongly associated with higher self-efficacy outcomes, suggesting meaningful interactions between psychological and metabolic health. This combined approach may improve exercise adherence and metabolic risk in aging populations.

Key Words: Metabolic Health, Overweight Older Adults, Resistance Training, Self-Efficacy

INTRODUCTION

Self-efficacy is a key determinant of exercise adoption and long-term adherence because it strengthens perceived control, intrinsic motivation, and the ability to overcome barriers, leading to persistent and habitual physical activity (9,25). According to Bandura's self-efficacy theory, individuals with high self-efficacy view exercise as achievable, show greater motivation, and persist despite their fatigue or lack of time; whereas, those with low self-efficacy tend to doubt their abilities, avoid physical activity, and withdraw when challenges arise (1). Older adults with higher self-efficacy demonstrate better motivation, stronger belief in their exercise capability, and healthier behaviors that support improvement in metabolic outcomes (5,26). In fact, the evidence shows that self-efficacy–based interventions effectively increase physical activity among overweight and obese older adults that result in greater energy expenditure, stronger adherence to exercise programs, and improved weight control (13,21).

Given these psychological and behavioral mechanisms, enhancing self-efficacy is particularly crucial for overweight and obese older adults, who often face multiple physical and motivational barriers to initiating and maintaining exercise (8). Resistance training, especially multi-joint or functional movements, has been widely recognized as an effective strategy to improve muscle strength, mobility, and metabolic health in overweight and obese aging populations (17,22). In addition, the evidence (23) shows that short-term high-load resistance training can normalize blood glucose levels in older adults and further attenuate age-related chronic inflammation, highlighting its substantial metabolic and anti-inflammatory benefits.

However, despite the well-documented benefits, adherence to resistance training among overweight and obese older adults remains low, largely due to limited confidence, fear of injury, and perceived difficulty (10). Therefore, integrating resistance training with self-efficacy–based strategies may provide a more comprehensive approach that not only promotes physical adaptations but also strengthens the psychological capacity required for sustained participation. This combined model may be particularly effective in improving metabolic outcomes, exercise adherence, and long-term health in older adults.

Nevertheless, although both theoretical and empirical evidence suggest that self-efficacy enhancement and resistance training independently contribute to improved health and exercise adherence, research examining their combined effects is still scarce. Whether an integrated resistance training program grounded in self-efficacy theory can produce additive or synergistic benefits, particularly in psychological constructs and metabolic risk factors, remains largely unexplored. In addition, the specific metabolic indicators that best predict improvements in knowledge, self-efficacy capability, and expected outcomes are yet to be identified.

METHODS

Subjects

Twenty-nine overweight older adults aged 60–75 years participated in the study. Fifteen participants were randomly allocated to the resistance training group (RT Group) and 14 to the resistance training group incorporating self-efficacy theory (RTS Group). Randomization was stratified by sex and age group (60–69 or 70–75 years). Participants had body mass index (BMI) values ranging from 23 to 27.4 kg/m². The **inclusion criteria** were as follows: (a) no history of uncontrolled diabetes, uncontrolled hypertension, cardiovascular disease, chronic obstructive pulmonary disease, or orthopaedic conditions that contraindicate exercise; (b) no use of weight-loss medication; (c) no participation in regular exercise or sports activities within the previous three months; and (d) low to moderate self-efficacy related to performing resistance training.

Procedures

Venous blood samples were taken pre- and post-intervention after an overnight fast of at least 8 hours. Participants completed the PAR-Q+ and a self-efficacy questionnaire specific to multi-joint exercise. Resting heart rate and blood pressure were measured in a seated position using a semi-automated monitor (Omron HEM-7120, Japan), followed by sequential assessments of body composition and physical function. During the intervention phase, participants in the resistance training group (RT Group) performed only the muti-joint resistance training (RT), while those in the muti-joint resistance training with self-efficacy theory group (RTS Group) participated in the same program with the addition of self-efficacy strategies.

Intervention

The RT Group in 12 weeks, 3 times/week, each session lasting 60 minutes (10-min warm-up, 40-min exercise, 10-min cool-down). Each session included 8 exercises: (a) shoulder press with chair squats; (b) standing row with high knees; (c) triceps extension with chair squats; (d) standing front raise with hip extension; (e) calf raise with shrugs and chair squats; (f) front lunge with lateral arm raise; (g) standing leg curls with bicep curls; and (h) split squat with bicep curls with 2 sets of 10 repetitions (progressively increased over time) and the RTS Group received the same exercise program as the RT Group, with additional components based on Bandura's self-efficacy theory strategies aimed at enhancing self-efficacy throughout the program include four primary sources: (a) mastery experience; (b) vicarious experience; (c) verbal persuasion; and (d) emotional arousal by stimulating self-efficacy while performing multi-joint exercises simultaneously.

Measurement

The outcome measures, which focused on evaluating self-efficacy in muti-joint exercise, body composition and blood chemistry, were administered at pre-test and post-test.

Self-Efficacy in Multi-Joint Exercise Questionnaire

The self-efficacy capability questionnaire used for designing multi-joint exercise programs in overweight older adults demonstrated strong reliability. When tested in a sample of 40 participants, the instrument showed excellent internal consistency, with a Cronbach's alpha of 0.90. Subscale reliability values were 0.72 for knowledge, 0.88 for self-efficacy capability, and 0.76 for expected outcomes, indicating that the questionnaire is a dependable tool for evaluating exercise planning competencies. The scoring framework was developed using a modified criterion-referenced approach, informed by Bloom's taxonomy and associated evaluation principles (2). The questionnaire consists of 4 parts were as follows.

- The *first part* gathered general and health information, including name, age, underlying diseases, and self-care through exercise.
- The *second part* assessed knowledge about multi-joint exercises using a multiple-choice format, with a total of 10 questions. Each question had two answer choices: "Yes" and "No". The scoring criteria are as follows: answering "Yes" earned 1 point, while answering "No" earned 0 points. A low level is 0–4.9, a medium level is 5–7.9, and a high level is 8–10.

- The *third part* assessed self-efficacy in multi-joint exercises, and the fourth part assessed perceived outcomes of multiple-choice exercises, both using a multiple-choice format with a total of 10 questions. Each question had 3 answer choices: "Yes", "Unsure", and "No". The questions included both positive and negative statements. The scoring criteria are as follows: for positive statements, answering "Yes" earned 3 points, "Unsure" earned 2 points, and "No" earned 1 point; for negative statements, the scoring is reversed: "Yes" earned 1 point, "Unsure" earned 2 points, and "No" earned 3 points. The scoring range is 10–30 points, categorized into 3 levels: a low level (10–16), a medium level (17–24), and a high level (25–30).

Body Composition

Body composition was assessed using a bioelectrical impedance analyzer (BIA; Omron HBF-375, Japan), which provided measurements of percentage body fat, fat mass, fat-free mass, and muscle mass.

Blood Collection and Biochemical Analysis

Venous blood samples were collected by a certified medical technologist from the antecubital vein after an overnight fasting period of at least 8 hours. Blood for glucose and lipid profile analyses was collected into serum separator tubes, while blood for HbA1c analysis was collected into dipotassium ethylenediaminetetraacetic acid (K2EDTA) tubes. All biochemical analyses were performed immediately following collection at a certified clinical laboratory within the Faculty of Allied Health Sciences, Chulalongkorn University, Pathumwan, Thailand.

Fasting plasma glucose (FPG) and lipid profiles, including total cholesterol, triglycerides, HDL-c, and LDL-c, were measured using an automated chemistry analyzer (Beckman Coulter AU480, USA) with enzymatic colorimetric techniques. The intra-assay coefficient of variation for hs-CRP was below 5%. All biochemical analyses were conducted following manufacturer protocols and standard quality control procedures. Blood samples were processed and analyzed within 2 hours of collection to maintain measurement accuracy.

Statistical Analyses

Statistical analyses were performed using SPSS (version 26; IBM Corp., Armonk, NY, USA). The normality of each variable was evaluated using the Shapiro-Wilk Test, and homogeneity of variance was assessed using the Levene's Test. Blood chemistry and self-efficacy related to multi-joint exercise were expressed as percent change scores from pre- to post-intervention. Between-group differences were analyzed using independent *t*-tests for variables that met normality assumptions; whereas, the Mann–Whitney U Test was used for non-normally distributed data. Effect sizes were calculated using Cohen's d for parametric tests and rank-biserial correlation for nonparametric comparisons. Statistical significance was set at a two-tailed $P < 0.05$. Pearson's correlation coefficient was used to examine relationships among normally distributed variables. Multiple regression analyses were conducted to identify metabolic predictors of self-efficacy outcomes. Variables that failed to meet normality assumptions were log-transformed prior to regression analysis. All regression models were checked for multicollinearity using variance inflation factors (VIF < 10) and for independence of residuals using the Durbin–Watson statistic.

RESULTS

Participant Characteristics

Twenty-nine overweight older adults completed the intervention (RTS, n = 15; RT, n = 14). As shown in Table 1, there were no meaningful baseline differences between the Groups in age, sex distribution, body weight, height, BMI, percentage body fat, fat mass, fat-free mass, skeletal muscle mass, resting heart rate, and resting blood pressure.

Table 1. General Physiological Characteristics and Body Composition of the RTS and the RT Groups.

Variables	RTS (n = 15)	RT (n = 14)
Age (yrs)	68 ± 3.35	67 ± 5.37
Sex	Male = 1, Female = 14	Male = 2, Female = 12
Body Weight (kg)	58.83 ± 5.62	61.55 ± 5.07
Height (cm)	155 ± 6.01	151 ± 26.04
Body Mass Index (kg/m²)	24.55 ± 1.06	24.74 ± 1.00
Percent Body Fat (%)	35.34 ± 3.41	36.01 ± 2.25
Fat Mass (kg)	20.73 ± 2.52	22.16 ± 2.22
Fat-Free Mass (kg)	38.10 ± 4.76	39.39 ± 3.61
Skeletal Muscle Mass (kg)	13.39 ± 2.26	13.98 ± 1.81
HR at Rest (bpm)	71.93 ± 9.20	69.43 ± 10.61
SBP at Rest (mmHg)	128.00 ± 13.56	129.71 ± 17.55
DBP at Rest (mmHg)	77.27 ± 7.06	79.29 ± 10.99

The data are presented as the mean ± SD for RTS: n = 15, RT: n = 14. **RTS** = Resistance training combined with self-efficacy theory, **RT** = Resistance training, **HR** = Heart Rate, **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure, **BMI** = Body Mass Index.

Changes in Self-Efficacy Outcomes and Metabolic Variables

Table 2 summarizes the pre- and post-intervention changes in self-efficacy outcomes and blood biochemistry. Compared with the RT Group, the RTS Group showed significantly greater improvements in knowledge (mean %Δ 74.92% vs. 23.20%, P = 0.019) and self-efficacy capability (41.62% vs. 28.37%, P = 0.048). Expected outcomes increased in both Groups, but the between-group difference in percent change was not significant (P = 0.171).

For metabolic outcomes, fasting glucose showed a significantly more favorable response in the RTS Group than in the RT Group. Glucose remained essentially unchanged in the RTS Group (0.86% increase); whereas, it increased by 8.15% in the RT Group, yielding a significant between-group difference (P = 0.014). Percent changes in HDL-c and hs-CRP did not differ significantly between Groups (P = 0.274 and P = 0.600, respectively).

Table 2. Changes in Self-Efficacies and Blood Biochemistry Before and After the Intervention in the RTS and the RT Groups.

Variables	RTS (n = 15)			RT (n = 14)			p
	Pre-Test Mean ± SD	Post-Test Mean ± SD	%Δ Change	Pre-Test Mean ± SD	Post-Test Mean ± SD	%Δ Change	
Knowledge (score)	6.07 ± 1.62	9.73 ± 0.46	74.92†	6.29 ± 1.49	7.36 ± 2.02	23.20†	0.019*
Self-Efficacy capability (score)	21.47 ± 2.33	30.00 ± 0.00	41.62†	21.21 ± 1.93	27.07 ± 2.37	28.37†	0.048*
Expected Outcomes (score)	27.87 ± 3.02	29.87 ± 0.35	8.53†	27.21 ± 2.72	27.79 ± 1.97	2.77†	0.171
HDL-c (mg/dL)	55.87 ± 13.56	55.53 ± 11.00	-0.61	61.14 ± 13.46	60.71 ± 13.84	0.17	0.274
Glucose (mg/dL)	92.07 ± 12.30	92.53 ± 10.36	0.86†	96.86 ± 16.61	104.50 ± 17.93	8.15†	0.014*
hs-CRP (mg/L)	1.55 ± 1.54	0.96 ± 0.59	-2.16†	1.80 ± 1.34	2.4 ± 3.58	35.0†	0.600

The data are presented as the mean ± SD for RTS: n = 15, RT: n = 14. **RTS** = Resistance training combined with self-efficacy theory, **RT** = Resistance training, **HDL-c** = High-Density Lipoprotein Cholesterol**,** hs-CRP High-Density Lipoprotein Cholesterol, * = Significance level was set at P < .05, † = Indicates statistical test used for %Δ change (*t* = independent samples *t*-test; U = Mann–Whitney U Test).

Correlation Analyses

Figures 1 and 2 illustrate the relationships between self-efficacy outcomes and metabolic variables in each Group. In the RTS Group (Figure 1), knowledge was strongly and positively correlated with HDL-c (r = 0.898, P < 0.001) and strongly and inversely correlated with fasting glucose (r = −0.935, P < 0.001). Expected outcomes showed a very strong negative correlation with fasting glucose (r = −0.992, P < 0.001) and a strong positive correlation with HDL-c (r = 0.945, P < 0.001). Self-efficacy capability was moderately and inversely associated with fasting glucose (r = 0.519, P = 0.024).

Overall, these findings indicate that the combined program incorporating self-efficacy strategies (RTS) produced greater improvements in self-efficacy outcomes and a more favourable fasting glucose response than resistance training alone, and that HDL-c and fasting glucose are strongly related to self-efficacy-related outcomes in both Groups.

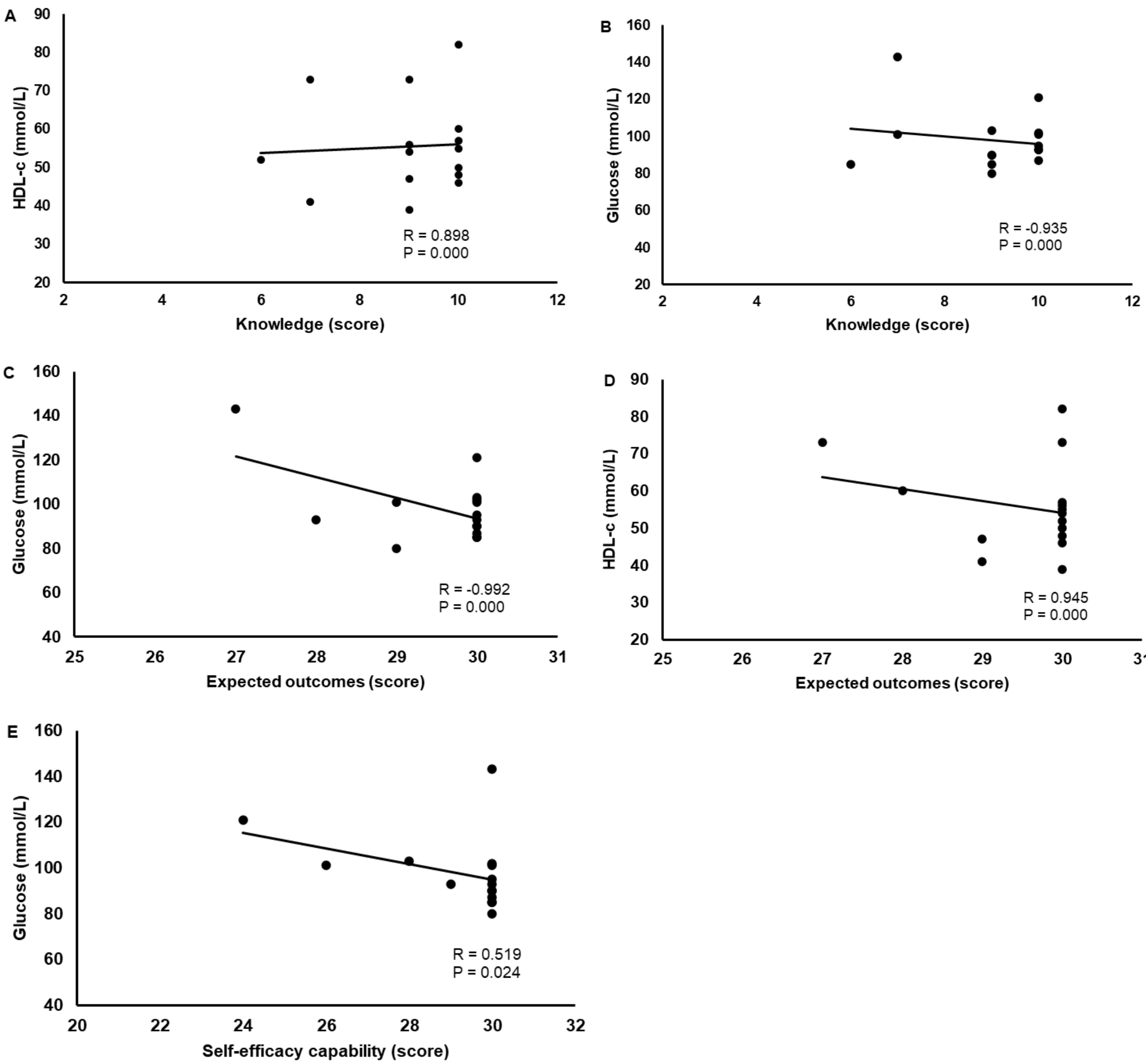

Figure 1. Correlations Between Self-Efficacy Outcomes (Knowledge, Self-Efficacy Capability, and Expected Outcomes) and Metabolic Variables (HDL-c and Fasting Glucose) in the RTS Group. (A) Correlation between knowledge score and HDL-c levels, (B) Correlation between knowledge score and fasting glucose levels, (C) Correlation between expected outcomes and fasting glucose levels, (D) Correlation between expected outcomes and HDL-c levels, (E) Correlation between self-efficacy capability and fasting glucose levels. Pearson’s correlation coefficients (R) and P-values are presented in each plot.

In the RT Group (Figure 2), similar patterns were observed. Knowledge was positively correlated with HDL-c ($r = 0.917$, $P < 0.001$) and negatively correlated with fasting glucose ($r = −0.903$, $P < 0.001$). Expected outcomes were strongly associated with both higher HDL-c ($r = 0.952$, $P < 0.001$) and lower fasting glucose ($r = −0.951$, $P < 0.001$). Self-efficacy capability was positively correlated with HDL-c ($r = 0.523$, $P = 0.028$) and fasting glucose ($r = 0.674$, $P = 0.004$).

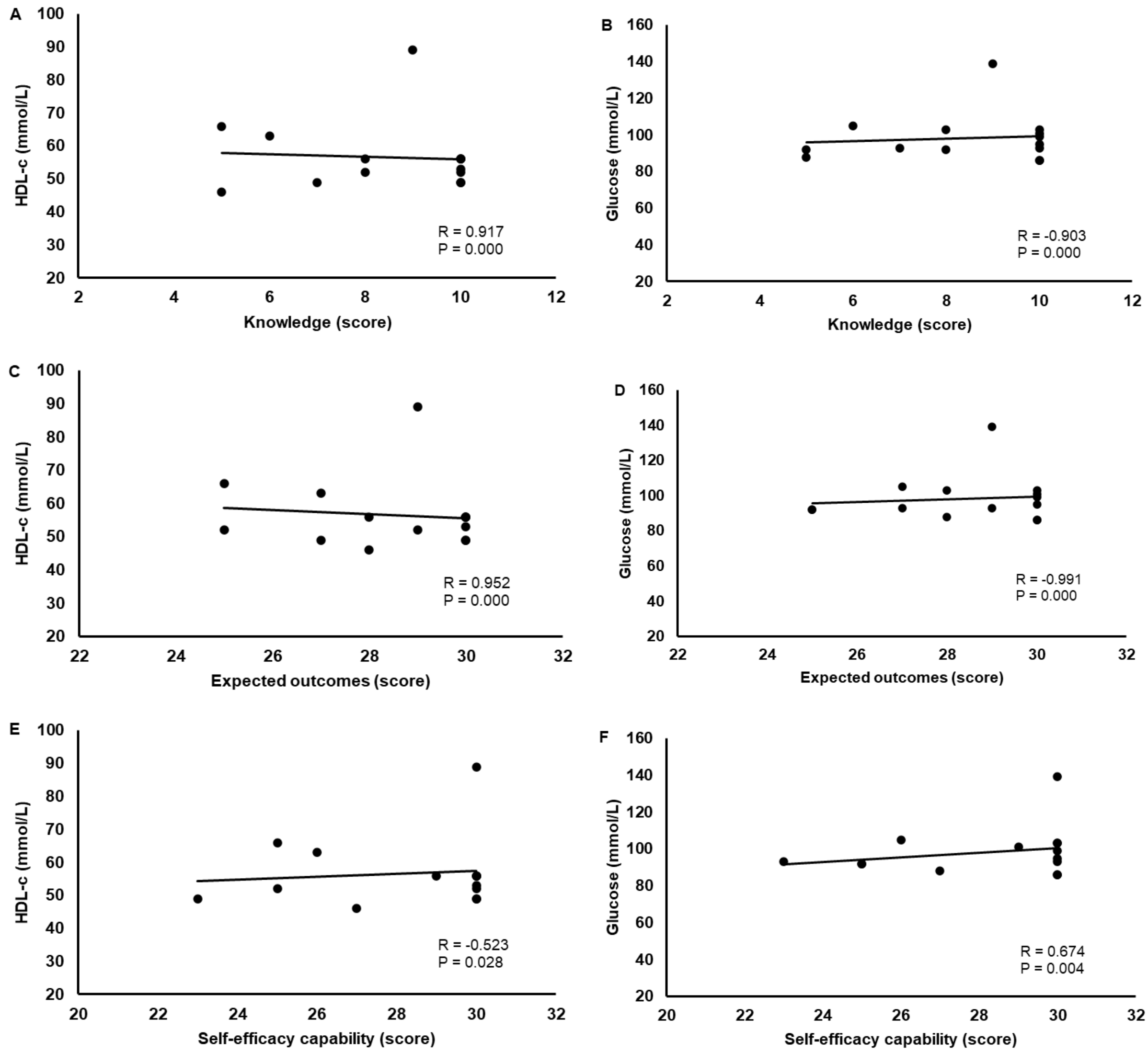

Figure 2. Correlations Between Self-Efficacy Outcomes (Knowledge, Self-Efficacy Capability, and Expected Outcomes) and Metabolic Variables (HDL-c and Fasting Glucose) in the RT Group. (A) Correlation between knowledge score and HDL-c levels, (B) Correlation between knowledge score and fasting glucose levels, (C) Correlation between expected outcomes and HDL-c levels, (D) Correlation between expected outcomes and fasting glucose levels, (E) Correlation between self-efficacy capability and HDL-c levels, (F) Correlation between self-efficacy capability and fasting glucose levels Pearson's correlation coefficients (R) and p-values are presented in each plot.

Multivariate Regression Analyses

Multiple regression models were used to identify metabolic predictors of self-efficacy outcomes in each Group (Tables 3 and 4). In the RTS Group, the overall models for knowledge, self-efficacy capability, and expected outcomes were all significant (knowledge: $R = 0.937$, $R^2 = 0.878$, $P < 0.001$; self-efficacy capability: $R = 0.781$, $R^2 = 0.610$, $P = 0.020$; expected outcomes: $R = 0.993$, $R^2 = 0.986$, $P < 0.001$).

Table 3. Multiple Regression Analysis of Metabolic Predictors on Knowledge, Self-Efficacy Capability, and Expected Outcomes in the RTS and RT Groups.

Variables	RTS (n = 15)			RT (n = 14)		
	β	*t*	P	β	*t*	P
Knowledge						
HDL-c	**0.094**	**0.279**	**0.786**	**0.632**	**1.994**	**0.074**
Glucose	**-0.858**	**-2.528**	**0.028**	**-0.251**	**-0.781**	**0.453**
hs-CRP	**-0.049**	**-0.451**	**0.661**	**0.185**	**1.647**	**0.130**
Self-Efficacy Capability						
HDL-c	**1.202**	**1.636**	**0.130**	**1.026**	**1.750**	**0.111**
Glucose	**1.637**	**2.217**	**0.049**	**1.709**	**2.877**	**0.016**
hs-CRP	**-0.099**	**-0.419**	**0.683**	**0.227**	**1.091**	**0.301**
Expected Outcomes						
HDL-c	**0.024**	**0.209**	**0.838**	**0.178**	**1.559**	**0.150**
Glucose	**-0.980**	**-8.591**	**0.000**	**-0.817**	**-7.045**	**0.000**
hs-CRP	**-0.042**	**-1.156**	**0.272**	**0.019**	**0.466**	**0.651**

β = standardized regression coefficient; ***t*** = t-statistic; P = significance level. **RTS** = Resistance training combined with self-efficacy theory; **RT** = Resistance training. **HDL-c** = High-Density Lipoprotein Cholesterol; **hs-CRP** = high-sensitivity C-reactive protein. Metabolic predictors included HDL-c, fasting glucose, and hs-CRP. *Significant predictors at P < .05 are indicated in bold.

Table 4. Multivariate Regression Models Examining Metabolic Determinants of Knowledge, Self-Efficacy, and Expected Outcomes in the RTS and RT Groups.

Statistic	R	R^2	Adjusted R^2	F(df)	p
RTS (n = 15)					
Knowledge	**0.937**	**0.878**	**0.845**	**26.351(3,11)**	**0.000****
Self-Efficacy capability	**0.781**	**0.610**	**0.493**	**5.209(3,11)**	**0.020***

Statistic	R	R^2	Adjusted R^2	F(df)	p
Expected Outcomes	**0.993**	**0.986**	**0.982**	**262.013(3,11)**	**0.000****
RT (n = 14)					
Knowledge	**0.941**	**0.886**	**0.852**	**25.874(3,10)**	**0.000****
Self-Efficacy Capability	**0.649**	**0.422**	**0.264**	**2.672(3,10)**	**0.099**
Expected Outcomes	**0.993**	**0.985**	**0.981**	**220.909(3,10)**	**0.000****

F(df) = F statistic with numerator and denominator degrees of freedom. **RTS** = Resistance training combined with self-efficacy theory; **RT** = Resistance training. All regression models included three metabolic predictors (HDL-c, glucose, and hs-CRP). *Significance level set at P < .05. **Significance level set at P < .01.

Within these models, fasting glucose emerged as the primary metabolic predictor. Lower fasting glucose significantly predicted higher knowledge ($\beta = -0.858$, $P = 0.028$) and higher expected outcomes ($\beta = -0.980$, $P < 0.001$), while higher fasting glucose significantly predicted greater self-efficacy capability ($\beta = 1.637$, $P = 0.016$). HDL-c and hs-CRP did not reach statistical significance in the RTS Group.

In the RT Group, the multivariate models for knowledge and expected outcomes were also significant (knowledge: $R = 0.941$, $R^2 = 0.886$, $P < 0.001$; expected outcomes: $R = 0.993$, $R^2 = 0.985$, $P < 0.001$); whereas, the model for self-efficacy capability did not reach significance ($p = 0.099$). In the RT Group, fasting glucose again acted as a significant predictor of expected outcomes ($\beta = -0.817$, $P < 0.001$), while HDL-c and hs-CRP were not significant predictors of any outcome.

DISCUSSION

The present study investigated the combined effects of resistance training and self-efficacy–based strategies on psychological outcomes and metabolic indicators in overweight older adults. The primary findings revealed that the incorporation of self-efficacy strategies (RTS Group) elicited greater improvements in knowledge and self-efficacy capability, as well as a more favorable fasting glucose response, compared with resistance training alone. Additionally, metabolic variables, particularly HDL-c and fasting glucose, were strongly related to self-efficacy outcomes in both Groups.

Self-Efficacy Outcomes

Consistent with Bandura's self-efficacy theory, the RTS Group demonstrated significantly greater gains in knowledge and self-efficacy capability compared with the RT Group. These improvements likely reflect the influence of mastery experiences, goal-setting, and verbal persuasion integrated into the RTS intervention (1). Prior research has shown that self-efficacy, based programs enhance exercise-related confidence, motivation, and behavioral engagement in older adults (7,24,26), particularly those with overweight or obesity (6). The current findings extend this evidence by showing that self-efficacy strategies embedded within resistance training yield superior psychological benefits relative to exercise alone. Interestingly, expected outcomes improved in both Groups without significant between-group differences. This may suggest that participation in a structured, supervised exercise program, regardless of psychological components, enhances individuals' anticipation of positive health benefits. Nevertheless, the markedly larger percent change in the RTS Group indicates that combined interventions may still offer incremental advantages. This is consistent with previous research indicating that integrating exergames with self-efficacy theory can effectively encourage greater exercise participation among older adults (4).

Metabolic Adaptations

Fasting glucose exhibited a notably better response in the RTS Group, remaining nearly unchanged; whereas, the RT Group showed a substantial increase. This suggests that increased self-efficacy may indirectly influence glucose regulation, possibly through improved adherence, greater effort during training, enhanced recovery, or stronger behavioral consistency outside of training sessions (24). The finding aligns with prior evidence indicating that resistance training improves glycemic control in older adults and that psychological readiness can amplify the physiological benefits of exercise (14,16,18).

In contrast, changes in HDL-c and hs-CRP did not differ significantly between Groups, due to their moderate intercorrelations, resulting in non-significant changes despite their psychological relevance. Nevertheless, their strong correlations with self-efficacy indicators highlight the interplay between metabolic health and psychological constructs in overweight older adults. This aligns with previous research indicating that self-efficacy is an important predictor of clinically relevant physical activity change in overweight and obese individuals. Furthermore, promoting general self-efficacy provides additional benefits for healthy ageing, as it enhances ageing and health perceptions, supports positive health behaviors, strengthens psychological well-being, and improves the ability to cope with physical decline in older adults (19,20).

Predictive Role of Metabolic Variables

Multiple regression analyses identified fasting glucose as the strongest metabolic predictor of psychological outcomes in both Groups. Lower glucose predicted higher knowledge and expected outcomes in the RTS Group, and similarly predicted expected outcomes in the RT Group. These findings highlight a potential bidirectional relationship: while exercise and self-efficacy may improve metabolic health, better metabolic profiles may also facilitate psychological and cognitive engagement, thereby reinforcing self-efficacy (3,11). HDL-c and hs-CRP did not emerge as significant independent predictors in the regression models. However, their strong correlations with psychological outcomes suggest that their effects may be attenuated when considered simultaneously with fasting glucose (12,15).

Correlation Patterns

The correlation analyses provide additional insight into the relationship between psychological and metabolic variables. In both Groups, higher HDL-c levels were strongly associated with higher knowledge and expected outcomes; whereas, fasting glucose exhibited robust inverse correlations with these outcomes. These findings reinforce the notion that favorable metabolic profiles may interact with psychological readiness to influence exercise behavior and overall health in overweight older adults (27,28). Notably, self-efficacy capability demonstrated moderate correlations with both HDL-c and fasting glucose, suggesting that emotional and behavioral confidence may be more sensitive to metabolic changes than knowledge alone 1,14).

Strengths and Practical Implications

A major strength of the study is the integration of a theory-driven psychological component with functional multi-joint resistance training, an approach that reflects a realistic and practical model for community-based exercise programs. The findings underscore the importance of enhancing self-efficacy in older adults with overweight and obesity, who often face multiple barriers to exercise initiation and adherence. Implementing self-efficacy strategies in exercise programs may improve not only psychological readiness but also metabolic outcomes, particularly glycemic control.

Limitations

Some methodological limitations of this study should be acknowledged. First, the relatively modest sample size may constrain the external validity of the findings and limit their generalizability beyond the study population. Second, dietary intake and habitual physical activity outside the intervention period could not be fully controlled, which is a common challenge in community-based research and may have introduced residual variability in metabolic outcomes. Finally, the intervention duration may not have been sufficient to elicit measurable changes in certain biomarkers, particularly HDL-c and hs-CRP, which are known to respond more slowly to lifestyle interventions.

CONCLUSIONS

This study demonstrates that integrating self-efficacy–based strategies with functional resistance training yields greater improvements in psychological outcomes and fasting glucose regulation than resistance training alone in overweight older adults. The strong associations between metabolic indicators and self-efficacy outcomes highlight the interaction between psychological readiness and metabolic health. These findings support the use of combined psychological and resistance training approaches to enhance exercise adherence and metabolic benefits in aging populations.

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The Effects of Core Muscle Training on Core Muscle Stability and Vertical Jump Performance in Male Basketball Players

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ABSTRACT

Warunee Kitraksa, Suphawadee Kasikam, Suttirak Nasome, Chonapha Sitthang. The purpose of this study was to investigate the effects of core muscle training on core muscle stability and vertical jump performance in male basketball players. Twenty-four male basketball players 15 to 18 years of age from Udonpittayanukul School participated in the study. They were assigned to an Experimental Group (n = 12) and a Control Group (n = 12). Core muscle stability was assessed using the Elbow Plank Test. Vertical jump performance was measured using the Countermovement Jump Test. Assessments were conducted before and after the training intervention. The core muscle training program was implemented over a 6-week period with training sessions conducted 3 times per week. Within-group comparisons were analyzed using paired *t*-tests, while between-group comparisons were analyzed using independent-samples *t*-tests. The level of statistical significance was set at $P < 0.05$. The results indicated that core muscle training led to significant improvements in both core muscle stability and vertical jump performance in the Experimental Group following the intervention ($P < 0.05$). In post-training comparisons between Groups, a significant difference was observed in core muscle stability ($P < 0.05$); whereas, no significant difference in vertical jump performance was found between the Experimental and Control Groups, although an increasing trend was observed. These findings suggest that the 6-week core muscle training program developed in this study is an appropriate approach for enhancing core muscle stability and vertical jump performance in male basketball players. In conclusion, core muscle training may contribute to improved movement efficiency in basketball players, and it is recommended that such training be incorporated into regular basketball training programs to support long-term physical development.

Key Words: Basketball Players, Core Muscle, Core Muscle Stability, Vertical Jump Performance

INTRODUCTION

Basketball is a high-intensity sport characterized by continuous and complex movements throughout competition, including jumping, sprinting, rapid changes of direction, sudden acceleration and deceleration, lateral movements, and physical contact with opponents. These movement patterns require efficient coordination between the neuromuscular system and the musculoskeletal system to maintain performance under dynamic conditions (4,7). Consequently, physical fitness plays a critical role in basketball performance, particularly in regards to components such as speed, muscular strength, endurance, agility, flexibility, as well as jumping ability and balance, which directly influence competitive performance (10). In addition, the physical demands of basketball can be evaluated through physiological responses, including sustained high blood lactate concentrations and elevated heart rate, as well as activity-based indices such as total distance covered, high-speed running distance, and the frequency of intense accelerations and decelerations (8). These indicators reflect the high energy expenditure and the rapidly changing movement patterns that are inherent in basketball performance.

Given the movement characteristics and physical demands of basketball, most actions require effective trunk control and efficient transfer of force from the lower to the upper body. These abilities rely fundamentally on trunk stability, with the core muscles functioning as a central link for force transmission and postural control. In particular, the core musculature contributes to maintaining balance, stabilizing body alignment, and enhancing lower-limb explosive power during jumping tasks, which are essential skills in basketball such as rebounding, shot blocking, and shooting. Previous studies have reported positive associations between core muscle strength and stability and measures of muscular power and vertical jump performance, as improved core function enhances the efficiency of the stretch–shortening cycle and reduces force dissipation during movement (2,5). Therefore, the development of core muscle strength is considered an important component in improving physical performance and vertical jump ability in basketball players.

Core muscles refer to the group of muscles located in the central region of the body that serve as the foundation for movement control and force transfer between the upper and lower extremities. These muscles include the deep abdominal and spinal stabilizers that include the transversus abdominis, multifidus, diaphragm, and the pelvic floor muscles, which work synergistically to maintain trunk and spinal stability. Core musculature plays a vital role in movement control, postural stability, and injury prevention, particularly during complex movements that involve rapid direction changes, running, and jumping, which are fundamental actions frequently observed in competitive sports (12). In basketball, core muscles are especially important since they serve as the central component for maintaining posture, balance, and efficient energy transfer between the lower and upper body. Adequate core strength and stability contribute to improved movement efficiency, reduced postural instability, and enhanced balance and jumping performance. These findings are consistent with those reported by Willardson in 2007 (12), who suggested that core strength training may enhance explosive jump performance and support the execution of essential basketball skills such as scoring, rebounding, and shot blocking.

Core stability refers to the ability of the core musculature to control and support the spine and pelvis in both static and dynamic conditions. This capacity plays a crucial role in postural control, balance, and force transfer within the kinetic chain, particularly in sports that require explosive movements and rapid changes of direction such as basketball (7,9). Vertical jump performance, which is a key indicator of lower-limb muscular power, is closely associated with speed, agility, and sport-specific skill execution. The effectiveness of jumping performance depends on muscular strength, postural stability, and the efficient transfer of energy from the core to the lower extremities (5). In basketball, effective jumping ability supports essential game-related actions that include rebounding, shot blocking, and scoring, all of which require precise trunk control (6).

Yet, despite its importance, many athletes tend to prioritize the training of large muscle groups over core muscle training, which may result in reduced movement stability and an increased risk of injury. Since previous research has suggested that core muscle training can enhance jumping performance and contribute to a decrease in the risk of injury, investigating the effects of core muscle strength training on core stability and vertical jump performance is warranted to better understand its role in enhancing competitive performance among male basketball players.

METHODS

Subjects

The participants in this study were male basketball players 15 to 18 years of age who voluntarily agreed to participate. Sample size estimation was conducted using an a priori power analysis with G*Power software (version 3.1.9.2), with the effect size set at 1.5 and statistical power set at 0.95. The analysis indicated that a minimum of 12 participants per group was required, resulting in a total sample size of 26 participants. The participants were allocated into 2 groups: the Experimental Group (n = 12), which completed a structured pre-training intervention in addition to regular basketball training, and the Control Group (n = 12), which continued regular basketball training only. Group allocation was performed using a systematic randomization procedure. Prior to randomization, all the participants underwent baseline testing of core muscle stability performance. Then, they were ranked according to their test performance from highest to lowest, and alternately assigned to the Experimental and Control Groups to ensure comparable baseline characteristics between the Groups. This study was approved by the Human Research Ethics Committee of UdonThani Rajabhat University (Ethical approval number: 0622.7/367 [Thai]).

Inclusion Criteria: The eligible participants were male basketball players aged 15 to 18 years who: (a) had served as official school representatives in formal interscholastic competitions; (b) were in good physical health with no medical conditions; and (c) provided voluntary consent to participate. The participants were excluded from the study if they: (a) sustained an injury preventing continued participation; (b) missed 2 or more of the 18 training sessions conducted over a 6-week period; or (c) withdrew consent at any stage of the study.

Experimental Design

Training Protocol

The Experimental Group participated in a structured core muscle strength training program in addition to regular basketball practice. The intervention was conducted over a period of 6 weeks with training sessions that were approximately 45-minute performed 3 times per week. Prior to each training session, the participants completed a dynamic warm-up that lasted 5 to

10 minutes. No cool-down was performed following the intervention, given that the participants subsequently continued with their regular school basketball practice.

The training program consisted of 5 core exercises: Dead Bug, Bird Dog, Russian Twist, Superman, and Side Plank. The training volume was progressively increased across the intervention period, with the participants performing 3 sets during weeks 1 and 2, 4 sets during weeks 3 and 4, and 5 sets during weeks 5 and 6. Each exercise was performed according to the prescribed number of repetitions or duration (Table 1).

All the training sessions were conducted at the same school training facility at similar times of day, and the sessions were supervised throughout the study by one principal investigator and 2 research assistants to ensure protocol adherence, correct exercise execution, and participant safety. The participants in the Control Group continued their regular basketball training program without additional core muscle training.

Table 1. Training Program.

Exercise	Repetitions / Duration	Sets	Rest Between Sets	Rest Between Exercises
1. Dead Bug	6 rep (or 45 sec)	W 1 – 2 (3 sets) W 3 – 4 (4 sets) W 5 – 6 (5 sets)	30 sec	1 min
2. Bird Dog	6 rep (or 45 sec)			
3. Russian Twist	20 rep (or 45 sec)			
4. Superman	20 rep (or 45 sec)			
5. Side Plank	45 sec			

Measurements

Core Muscle Stability

The Elbow Plank Test was used to assess core muscle stability, reflecting the ability to control and support the trunk as well as overall core muscle strength. For the test, the participants laid prone on the floor with both elbows positioned directly beneath the shoulders, legs fully extended, and toes in contact with the ground. The participants then engaged the core muscles and lifted the body to maintain a straight alignment from head to heels without elevating or lowering the hips. The test was terminated when the participants were no longer able to maintain the correct posture, and the maximum duration for which the position was held was recorded in seconds.

Vertical Jump Performance

The Countermovement Jump Test (CMJ) was used to assess vertical jump performance. Prior to the test, all the participants were provided with a clear explanation of the testing procedures, and the research assistants encouraged maximal effort during each trial. For the test, the participants stood upright and extended their dominant arm overhead alongside the ear, while the non-dominant hand was placed on the waist. Then, the participants performed a countermovement by flexing the knees and jumping vertically as high as possible. The jump height was determined by fingertip contact on a vertical measuring scale. Two trials were performed, and the highest jump height was recorded. Vertical jump height was calculated by subtracting the standing reach height from the maximal jump reach height, and the final value was recorded in centimeters.

Statistical Analyses

The data were analyzed using SPSS software (version 22). Descriptive statistics, including means and standard deviations (mean ± SD), were calculated for the participants' age, body weight, and height. Within-group differences in core muscle stability and vertical jump performance were analyzed using a paired-samples *t*-test. Between-group differences between the Experimental Group and the Control Group were analyzed using an independent-samples *t*-test. The level of statistical significance was set at $P < 0.05$.

RESULTS

Results indicated that there were no significant differences in baseline characteristics between the 2 Groups ($P > 0.05$). The participants consisted of 24 male basketball players who were equally allocated into 2 Groups. The Experimental Group (n = 12) had a mean age of 15.75 ± 1.13 yrs, body weight of 64.17 ± 13.53 kg, and height of 171.17 ± 7.75 cm. The Control Group (n = 12) had a mean age of 15.75 ± 1.21 yrs, body weight of 59.75 ± 12.03 kg, and height of 169.75 ± 9.63 cm (Table 2).

Table 2. The Physical Characteristics of the Participants.

Physical Characteristics	Experimental Group (n = 12) Mean ± SD	Control Group (n = 12) Mean ± SD	P - value
Age (yr)	15.75 ± 1.13	15.75 ± 1.21	1.00
Weight (kg)	64.17 ± 13.53	59.75 ± 12.03	.407
Height (cm)	171.17 ± 7.75	169.75 ± 9.63	.695

Table 3. Comparison of Mean Values between the Experimental and Control Groups Before Training and After Training. *P < .05 indicates statistically significant difference.

	Physical Characteristics	Experimental Group (n = 12) Mean ± SD	Control Group (n = 12) Mean ± SD	*t*	P - value
Before Training	Core Muscle Stability (sec)	95.4 ± 59.00	99.0 ± 53.30	-.161	.873
	Vertical Jump Performance (cm)	42.92 ± 6.94	45.33 ± 11.84	-.610	.548
After Training	Core Muscle Stability (sec)	138.0 ± 59.80	90.6 ± 39.40	2.302	.031*
	Vertical Jump Performance (cm)	49.75 ± 6.96	46.92 ± 9.01	.862	.398

The results indicate that before training no significant differences were observed between the Experimental Group and the Control Group in core muscle stability or vertical jump performance (P > 0.05). The Experimental Group was associated with a mean core muscle stability of 95.4 ± 59.0 sec and a vertical jump performance of 42.92 ± 6.94 cm, while the Control Group showed a mean core muscle stability of 99.0 ± 53.3 sec and a vertical jump performance of 45.33 ± 11.84 cm. After training, a significant between-group difference was observed in core muscle stability (P < 0.05); whereas, no significant difference was found in vertical jump performance (P > 0.05). The Experimental Group exhibited a mean core muscle stability of 138.0 ± 59.8 sec and a vertical jump performance of 49.75 ± 6.96 cm, while the Control Group showed a mean core muscle stability of 90.6 ± 39.4 sec and a vertical jump performance of 46.92 ± 9.01 cm (Table 3).

Table 4. Within-Group Comparison of Pre- and Post-Training Values of Core Muscle Stability and Vertical Jump Performance. *P < .05 indicates statistically significant difference.

	Physical Characteristics	Pre Test Mean ± SD	Post Test Mean ± SD	*t*	P-value
Experimental Group	Core Muscle Stability (sec)	95.4 ± 59.0	138.0 ± 59.8	2.219	.044*
	Vertical Jump Performance (cm)	42.92 ± 6.94	49.75 ± 6.96	3.908	.001*
Control Group	Core Muscle Stability (sec)	99.0 ± 53.30	90.6 ± 39.40	-1.078	.304
	Vertical Jump Performance (cm)	45.33 ± 11.84	46.92 ± 9.01	.997	.340

Within the Experimental Group, significant differences were observed in both core muscle stability and vertical jump performance after the 6-week training period (P < 0.05). Mean core muscle stability increased from 95.4 ± 59.0 sec before training to 138.0 ± 59.8 sec after training, while vertical jump performance increased from 42.92 ± 6.94 cm to 49.75 ± 6.96 cm. In contrast, no significant differences were found within the Control Group for either core muscle stability or vertical jump performance (P > 0.05). Mean core muscle stability changed from 99.0 ± 53.30 sec before training to 90.6 ± 39.40 sec after training, and vertical jump performance changed from 45.33 ± 11.84 cm to 46.92 ± 9.01 cm.

DISCUSSION

The purpose of this study was to examine the effects of core muscle strength training on core stability and vertical jump performance in male basketball players, as well as to compare training outcomes before and after the intervention and between the Experimental and Control Groups. The core training program employed in this study was designed to address key physical performance components relevant to basketball players. Although the program did not emphasize high training intensity or excessive training volume, it focused on fundamental exercises related to trunk control and movement that are associated with physical performance development and may contribute to injury risk reduction during basketball competition.

The findings of the present study suggest that the core muscle strength training program resulted in a statistically significant improvement in core muscle stability in the Experimental Group, as observed in both the within-group pre–post comparisons and the between-group comparisons with the Control Group. These results suggest that targeted core muscle training can effectively enhance the functional capacity of the core musculature (refer to Tables 3 and 4). The findings are consistent with the previous studies that reported core muscle training improved the body's ability to control and maintain appropriate trunk alignment under both static and dynamic conditions, thereby supporting force absorption, movement control, and overall muscular strength (1). Furthermore, several studies (3,6,11) have indicated that core muscle strength and stability play a crucial role in the coordinated function of multiple joints and muscle groups to generate, control, and transfer force during movement that is commonly described as the kinetic chain, which directly influences the efficiency of complex sport-specific movements.

In addition to the improvements in core stability, the results of the present study indicate that core muscle strength training was also associated with the enhancement in vertical jump performance among the basketball players. Within the Experimental Group, vertical jump performance after the intervention was significantly greater than before training. These findings are consistent with those reported by Sannicandro (11), who suggested that core stability training positively influenced jump performance in youth basketball players. Similarly, Yılmaz (13) reported that isometric core muscle training combined with basic basketball training was associated with improvements in explosive power and vertical jump ability in children and adolescents. Moreover, research published in the University of Foggia repository has highlighted the importance of core muscle training in force transfer and movement control, which are mechanisms that are closely related to jump performance in explosive sports such as basketball. These adaptations can be explained through the kinetic chain concept, which emphasizes the role of core stability in transferring force from the lower extremities through the trunk to the upper body during explosive movements.

Overall, the findings of this study indicate that a core muscle strength training program is associated with changes in both core stability and vertical jump performance in basketball players. The core musculature functions as a biomechanical link between the trunk and the extremities and plays a critical role in force transfer, balance maintenance, and postural control during activities requiring rapid movement and directional changes, such as dribbling, jumping, shooting, and defensive actions. Therefore, enhancing core muscle stability may contribute to improved movement efficiency in basketball players. Based on the present findings, it is recommended that core muscle training programs be incorporated into regular basketball training plans to establish a solid foundation of physical fitness and support long-term athletic development.

CONCLUSIONS

The present study suggested that a 6-week core muscle strength training program is associated with changes in core muscle stability and vertical jump performance in male basketball players, particularly in the Experimental Group that performed additional core training alongside regular basketball practice. These findings suggest that core muscle training focused on trunk control and fundamental movement patterns may contribute to physical performance components related to explosive movements in basketball. When implementing core muscle training programs, considerations should be given to athletes' age, skill level, and training context in order to appropriately support long-term physical development.

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Effects of an Aquatic Aerobic Exercise Program on Body Composition, Muscular Strength, and Power in Overweight Female College Students

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ABSTRACT

Kruatiwa N, Nak-eam S, Vongchaisub TS. Obesity has become a major public health concern in Thailand, particularly among female college students who face rapid weight gain and increased health risks due to sedentary lifestyles. While exercise is crucial for weight control, land-based activities can pose joint risks for overweight individuals. Thus, aquatic exercise has emerged as a low-impact alternative. The purpose of this study was to investigate the effects of an aquatic aerobic exercise program on body composition, muscular strength, and power in overweight female college students. Twenty female students (BMI 25.00–29.99 kg/m²) volunteered to participate in this study. The participants engaged in an 8-week aquatic aerobic exercise program conducted 3 times per week, with each 60-minute session monitored at a moderate-to-vigorous intensity (60–80% of maximal heart rate). Data were collected on percentage of body fat (PBF), maximal leg muscle strength (1RM), and muscular power using a Keiser A300 pneumatic leg press. Paired-sample *t*-tests were used for analysis, with statistical significance set at $P < 0.05$. The program produced significant reductions in PBF and significant improvements in absolute and relative strength and power ($P < 0.001$), demonstrating large effect sizes (Cohen's d = 0.88–1.57). These findings indicate that the aquatic aerobic exercise program effectively improves body composition, maximal strength, and power that supports its use as a comprehensive and joint-friendly training strategy for overweight young women.

Key Words: Aquatic Aerobic Exercise, Body Composition, Leg Muscle Strength, Obesity

INTRODUCTION

Gender is a significant determinant of overweight and obesity status. Previous studies indicate that women naturally accumulate more body fat than men due to distinct metabolic profiles and hormonal factors related to insulin resistance (10,17). In Thailand, obesity has become a major public health concern, ranking second in prevalence among ASEAN nations after Malaysia (12). This condition has a substantial impact on longevity, potentially reducing life expectancy by 7 to 10 years compared with individuals of normal weight. A primary driver of this epidemic is the modern sedentary lifestyle that is characterized by prolonged sitting and high-calorie diets. This issue is particularly pronounced during the transition from adolescence to university life. Female college students often experience a marked decline in physical activity due to academic demands and lifestyle changes, which lead to rapid weight gain and increases in the percentage of body fat (PBF) that exceed healthy thresholds. Consequently, they face an increased early risk of non-communicable diseases (NCDs), such as diabetes and hypertension.

Weight control through exercise is a cornerstone of intervention. Although land-based aerobic exercise is effective (23), it can pose challenges for overweight individuals due to the high impact on joints. Aquatic aerobic exercise has emerged as a superior alternative. The buoyancy of water reduces gravitational stress on the joints, thereby minimizing the risk of injury (7,20). In addition, the viscosity of water provides accommodating resistance, such that the harder one pushes the greater the resistance encountered. This unique property enables the simultaneous improvement of muscular strength and power, both of which are essential for functional capacity.

Previous research suggests that 8 to 12 weeks of aquatic exercise can significantly improve physical fitness, reduce PBF, and enhance muscle flexibility (7). Consistent with these findings, studies typically examine key physiological variables, including body composition, circulatory function, body mass index, and leg muscle strength the primary muscle group engaged during vertical movement in moderate-depth water (1,9,13). However, most existing studies focus primarily on obese, elderly, or clinical populations (1,3-5,9). Consequently, there remains a paucity of research specifically examining physiological adaptations, particularly regarding muscular power, in young, overweight female adults. While muscular power is a critical determinant of functional performance and movement efficiency, its adaptation to aquatic aerobic training in this population remains poorly understood.

Therefore, the purpose of this study was to investigate the effects of an aquatic aerobic exercise program on body composition, muscular strength, and power in overweight female college students. It is hypothesized that the intervention will significantly reduce PBF and enhance leg muscle strength and power in overweight female college students. The findings are expected to provide evidence-based guidelines for designing low-impact, high-efficiency exercise programs tailored to this specific population.

METHODS

Subjects

Twenty female students from the National Sports University (Bangkok Campus), aged 18 to 22 years, who were classified as overweight (BMI of 25.00–29.99 kg/m²), volunteered to participate in this study. The sample size was calculated using Cohen's methodology with a confidence level of 95%, a statistical power of 80%, and an effect size of 0.8 based on previous research (18). All the participants were free of underlying medical conditions or cardiovascular abnormalities that would contraindicate aquatic exercise. Exclusion criteria included the presence of skin diseases, open wounds, or infectious conditions that preclude entry into a swimming pool. All the participants were informed of the purpose, the procedures, and the potential risks prior to the study of which the protocol was approved by the Human Research Ethics Committee, Sirindhorn College of Public Health, Yala Province.

Procedures

The experimental procedures commenced with the preparation of the testing facility and equipment, followed by a detailed explanation of the research objectives and methodology to the participants, from whom written informed consent was obtained. Baseline demographic data that included age, height, weight, BMI, blood pressure (BP), and resting heart rate (Resting HR), were recorded. Prior to the intervention, all the participants underwent a pre-test assessment to measure PBF, as well as leg muscle strength and power. Subsequently, the participants engaged in an 8-week aquatic aerobic exercise program conducted 3 times per week (Monday, Wednesday, and Friday). Training was performed at a moderate water depth (between waist and chest level). Each 60-minute session was monitored to ensure that the training intensity was maintained within moderate-to-vigorous target zones of 60 to 80% of maximal heart rate in accordance with a previous study (2). Following the training period, post-test measurements for all variables were taken using the same protocols.

Measurements

Characteristics of the Participants

The participant characteristics, specifically body weight and BMI, were assessed using a body composition monitor (TANITA model BC-587; Japan). Systolic blood pressure (SBP), diastolic blood pressure (DBP) and resting HR were measured using an Omron HEM Series monitor (Japan).

Percentage of Body Fat (PBF)

PBF was assessed using a Lange skinfold caliper to measure skinfold thickness at 4 sites (biceps, triceps, subscapular, and suprailiac) on the right side of the body, which followed the protocol established by Durnin and Womersley (8). Body density was estimated from the logarithmic sum of these skinfolds and converted to percent body fat using Siri's equation. This method has been validated against underwater weighing that demonstrated correlation coefficients between 0.70 and 0.90, with a standard error of estimate of approximately ±3.5% for women and ±5.0% for men.

Muscular Strength

Maximal strength was assessed using a Keiser Air300 pneumatic leg press with the participants positioned at a 90° knee angle. To estimate the one-repetition maximum (1RM), the load-velocity (L-V) relationship was determined by performing concentric repetitions at maximal velocity across incrementally increasing loads of 20 to 30 kg increments. The limit load was calculated via linear regression using a velocity threshold of 0.23 $m \cdot sec^{-1}$. This method has demonstrated high validity (r = 0.95) and practically perfect reliability (ICC = 0.99) when compared to direct measurements (15). Relative 1RM was calculated by dividing the 1RM value by body weight.

Muscular Power

Lower-limb muscle power was assessed using the Keiser six-repetition power test on a Keiser Air300 pneumatic leg press. The participants were instructed to execute every repetition at maximal velocity. The protocol involved 2 distinct resistance levels: (a) low load set at approximately 10% of the estimated maximum resistance; and (b) high load set at approximately 80 to 90% with the participants performing 3 repetitions at each intensity for a total of 6 repetitions. Average peak power was calculated as the arithmetic mean of the peak power outputs obtained from all 6 repetitions. Subsequently, Relative average peak power was derived by normalizing the average peak power to the participant's body mass.

Statistical Analyses

All statistical analyses were performed using SPSS 20.0 (IBM Corp., Armonk, NY). The data were tested for normality using the Shapiro-Wilk test. Variables with a normal distribution were evaluated using paired sample *t*-tests; non-normally distributed data were evaluated with the Wilcoxon signed-rank test. The significance level was set at $P < 0.05$ for all comparisons. Effect sizes (ES) were calculated using the Cohen’s d method and were reported with the following thresholds: trivial (ES < 0.2), small (ES = 0.2 - 0.6), medium (ES = 0.6 - 1.2), and large (ES > 1.2) (11).

RESULTS

The descriptive statistics for the participants' physical characteristics and physiological measures are presented in Table 1. The study sample consisted of 20 participants with a mean age of 20.4 ± 1.0 years. The average height was 169.0 ± 2.6 cm, and the mean body weight was 80.7 ± 3.9 kg. The calculated BMI averaged 28.2 ± 1.2 kg/m², indicating that the participants were, on average, classified within the overweight category. Regarding physiological parameters, the mean Resting HR was 80.6 ± 6.9 bpm. SBP and DBP were 122.8 ± 7.2 mmHg and 78.3 ± 5.5 mmHg, respectively, which remained within the expected physiological ranges. These baseline measures serve to characterize the sample for the subsequent interpretation of the study results.

Table 1. Descriptive Characteristics of the Participants (Mean ± SD).

Variable	Total (n = 20)
Age (year)	20.4 ± 1.0
Height (cm)	169.0 ± 2.6
Weight (kg)	80.7 ± 3.9
BMI (kg/m^2)	28.2 ± 1.2

Resting HR (bpm)	80.6 ± 6.9
SBP (mmHg)	122.8 ± 7.2
DBP (mmHg)	78.3 ± 5.5

As presented in Table 2, paired-samples *t*-tests revealed significant improvements across all measured variables following the experimental intervention. Specifically, PBF decreased significantly from 33.8 ± 3.0% at baseline to 30.6 ± 2.7% post-intervention (t = 8.08, P < .001), indicating a large effect size (Cohen's d = 1.12). Concurrently, participants demonstrated substantial gains in muscular strength, with absolute 1RM increasing from 99.8 ± 7.6 kg to 106.6 ± 7.8 kg (t = −5.55, P < .001, d = 0.88) and relative 1RM improving from 1.24 ± 0.04 to 1.33 ± 0.07 times body weight (t = −5.73, P < .001, d = 1.57). In addition to strength gains, muscle power output also showed significant enhancement; Average peak power rose from 423.0 ± 30.8 watts to 476.5 ± 58.4 watts (t = −4.35, P < .001, d = 1.15), and relative average peak power increased from 5.24 ± 0.27 watts/kg to 5.96 ± 0.76 watts/kg (t = −4.47, P < .001, d = 1.26). These findings collectively suggest that the intervention was highly effective in improving body composition while simultaneously augmenting both maximal strength and power.

Table 2. Summary of Paired-Samples *t*-Tests.

Variable	Before Experiment (Mean ± SD)	After Experiment (Mean ± SD)	*t* - value	P-value	Cohen's d
PBF (percent)	33.8 ± 3.0	30.6 ± 2.7	8.08	<.001*	1.12
1RM (kg)	99.8 ± 7.6	106.6 ± 7.8	-5.55	<.001*	0.88
Relative 1RM (times body weight)	1.24 ± 0.04	1.33 ± 0.07	-5.73	<.001*	1.57
Average Peak Power (watts)	423.0 ± 30.8	476.5 ± 58.4	-4.35	<.001*	1.15
Relative Average Peak Power (watts per kg)	5.24 ± 0.27	5.96 ± 0.76	-4.47	<.001*	1.26

DISCUSSION

The present study examined the effects of an aquatic aerobic exercise program on body composition, muscular strength, and muscular power in overweight female college students. Participation in the program resulted in significant improvements across all primary outcomes, including reductions in PBF and increases in absolute and relative maximal strength, as well as absolute and relative power. Collectively, these findings are consistent with recent evidence indicating that water-based exercise interventions can improve body composition and selected neuromuscular outcomes when training volume and intensity are appropriately prescribed (7,25). This finding is particularly relevant for overweight young women since it indicates that aquatic aerobic exercise can simultaneously target metabolic health and neuromuscular performance within a single training modality.

A major finding of this study was the significant reduction in PBF following the aquatic aerobic exercise program. This magnitude of change is clinically and physiologically meaningful in overweight populations and aligns with contemporary meta-analytic evidence demonstrating the favorable effects of water-based exercise on body composition (7,25). The reduction in PBF observed in the present study supports the view that adequately dosed aquatic aerobic programs are capable of inducing meaningful reductions in body fat. Also, the improvements in neuromuscular function may increase exercise tolerance and facilitate participation in higher-intensity physical activity, thereby amplifying training-induced energy expenditure over time (25).

Regarding muscular strength, significant improvements were observed, as evidenced by increases in both absolute and relative 1RM. The larger effect observed for relative strength highlights the combined influence of strength gains and favorable body composition changes. These findings are particularly important for overweight individuals, given that relative strength is closely linked to functional capacity, mobility, and injury risk (24). Although aquatic aerobic exercise is not traditionally classified as resistance training, the continuous drag forces imposed by water appear sufficient to stimulate neuromuscular adaptation, especially in individuals with low-to-moderate baseline strength (16,22). Nevertheless, it should be acknowledged that maximal strength development is typically optimized through progressive resistance training with high external loads. Accordingly, aquatic aerobic exercise should be viewed as a complementary or preparatory modality rather than a replacement for traditional resistance training in strength-focused programs.

Participants also demonstrated significant improvements in muscular power following the aquatic aerobic exercise program. These findings suggest an enhanced capacity for rapid force production, which is a key determinant of functional performance (6,24). The aquatic environment may uniquely facilitate power development due to the velocity-dependent nature of water resistance. As movement speed increases, drag forces increase correspondingly, requiring rapid force production to overcome resistance. This characteristic provides a stimulus consistent with established models of power development that emphasize the interaction between force and velocity (6). Buoyancy further reduces impact forces and joint stress, enabling overweight individuals to perform faster and more explosive movements with reduced injury risk. The observed improvements in relative power are particularly meaningful, as power relative to body mass is strongly associated with performance in daily activities and dynamic movement tasks (24). Together, these findings suggest that aquatic aerobic exercise, when designed to incorporate higher-velocity movements and sufficient intensity, can serve as an effective stimulus for power development.

The concurrent improvements in body composition, muscular strength, and power observed in this study likely reflect the interaction of metabolic and neuromuscular mechanisms. Repeated exposure to water resistance may enhance motor-unit recruitment patterns and neuromuscular coordination, while the unstable and multidirectional aquatic environment challenges postural control and intermuscular synchronization (14,21). Simultaneously, the elevated energetic cost of aquatic movement and sustained exercise duration may promote favorable metabolic adaptations that collectively support improvements in physical performance. The mechanisms are consistent with earlier aquatic exercise research. A previous study reported that a 12-week aqua-aerobic exercise program improved health-related physical fitness and glycemic control in elderly patients with type 2 diabetes (19). Although the population differed from the present sample, the underlying neuromuscular and metabolic mechanisms of aquatic exercise appear transferable across age groups and health statuses.

Limitations in this Study

This study employed a one-group pretest–posttest design without a control group, which limits the ability to infer causality. Therefore, the findings should be interpreted as adaptations associated with the training. Although the sample size was modest, it was determined a priori via power analysis and was sufficient to detect meaningful within-subject changes. Finally, the results may not be generalizable to populations other than young, overweight women.

CONCLUSIONS

The aquatic aerobic exercise program examined in this study was associated with significant and practically meaningful improvements in body composition, maximal muscular strength, and muscular power in overweight female college students. These findings support the use of aquatic aerobic exercise as a comprehensive and joint-friendly training strategy for improving health- and performance-related fitness in overweight young women.

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The Influence of Knee Muscle Architecture and Isokinetic Strength on Sprint Performance

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ABSTRACT

Apibantaweesakul S, Somkla P, Apichatrotjanakul S, Raharn A, Lapmongkolnavin J, Kaewkun T, Phiboon J, Wichitwasutep P, Suttanon P. The quadriceps femoris and hamstrings are crucial muscle groups for generating force and propelling the body forward. Sprinters exhibit unique morphological characteristics in these knee muscles, which are linked to their performance. Although the rate of torque development (RTD) is a key indicator of rapid force production, the relationship between knee muscle architecture and muscle performance, including RTD, has not been thoroughly investigated in sub-elite sprinters. The purpose of this study was to examine the relationships among knee muscle architecture, isokinetic muscle strength, including RTD, and sprint performance in sub-elite Thai male 100-meter sprinters. This study employed a cross-sectional observational study. Eight sub-elite Thai male 100-m sprinters (the personal recorded best time <11.00 sec) participated in this study. Knee muscle architecture was assessed using ultrasonography. Fast-velocity isokinetic knee strength (at an angular velocity of 300°/sec) was measured with RTD analysis, followed by a 100-meter sprint performance test. The results demonstrated significant correlations between 100-m sprint velocity and knee flexion peak torque relative to body weight ($r = 0.81$, $P = 0.05$), as well as between the hamstring-to-quadriceps ratio and sprint performance ($r = 0.79$, $P = 0.02$). Additionally, knee extension RTD was associated with anterior thigh muscle thickness, peak torque, and time to peak torque; whereas, knee flexion RTD was related to peak torque angle and time to peak torque. Knee muscle architecture was not directly related to muscle strength or sprint performance in the sub-elite sprinters. Instead, sprint performance was associated with greater normalized knee flexor strength and a higher H:Q ratio, while RTD measures reflected rapid torque-generation capacity. These findings underscore the relevance of fast force production to sprint performance.

Key Words: Biceps Femoris, Health Determinants, Muscle Thickness, Rate of Torque, Ultrasonography,

INTRODUCTION

Due to the elite sprinters ability to generate high muscle forces, particularly in the lower limbs (12,29), sprint performance can reach up to 12 m/sec. Previous studies have shown that the quadriceps and hamstrings play a crucial role in running and influence athletic performance, particularly running strength and speed (7,18,41). The quadriceps muscles act during the initial stance phase, decelerating the body in preparation for push-off or forward acceleration, while the hamstrings function during the latter half of the swing phase and the first half of the stance phase, contributing to the generation of horizontal ground reaction force to propel the body forward (30,31). These muscles are frequently injured (13,15), reflecting the evidence of muscle activity during sprinting.

Several factors influence running speed, including running biomechanics (foot strike pattern, arm swing, stride length, stride frequency, joint range of motion, and ground impact force) (11, 31), sex (32), and muscle type (42). Muscle morphology and architecture describe structural characteristics such as muscle thickness, fascicle length, and pennation angle, which influence a muscle's capacity for force production and contraction velocity. Previous studies found that muscle size is related to running strength and speed (41). A smaller pennation angle is associated with faster running speeds because the pennation angle reflects the muscle's ability to contract quickly (19). Conversely, a larger pennation angle increases the muscle's cross-sectional area and the number of muscle fibers, allowing it to produce more force for movement (39). Long fascicles contain a large number of sarcomeres, which are essential for rapid muscle contraction, leading to greater force production and faster movement (24). It is concluded that muscle architecture and morphology are linked to sprinting performance as determinants of explosive strength.

Explosive strength is the ability to increase torque as quickly as possible during a rapid voluntary contraction, realized from a low level. Peak torque and the rate of torque development (RTD) reflect a dynamic component of muscle performance that is important for physical function (9,10,35). The rate of torque development, which is obtained from the torque-time curve recorded during explosive voluntary contractions (1). The capacity to produce torque at high velocity is important, given that the sprinting performance depends on the capacity to increase the torque in the early phase of the contraction (9).

Therefore, muscle architecture, strength, and specific variables such as RTD may enable athletes to perform skills efficiently and lead to the ability to achieve speed, which is crucial for sprinters. Although previous studies have examined knee peak torque and its ratio, limited research has explored the combined contribution of these variables. The purpose of this study was to examine the associations between sprint velocity, knee muscle strength, RTD, and muscle architecture in Thai sub-elite sprinters. We hypothesized that correlations would exist among muscle architecture, muscle strength, and sprint performance.

METHODS

Subjects

A total of eight Thai sub-elite male sprinters voluntarily participated in this study. Inclusion criteria required the athletes to be Thai national-level sprinters who trained at least 3 days per week and had a personal best of <11.00 sec in the 100-m sprint. Sub-elite status was defined as a season's best of 10.35–11.50 sec for the 100 m, or an equivalent 60-m/200-m performance according to International Association of Athletics Federations (IAAF) points (29). The participants engaged in at least 2 sprint-specific training sessions per week (ranged 5–7 sessions/week) and one resistance training session per week (ranged 1–3 sessions/week). Participants were excluded if they had any lower extremity injuries or were on continuous medication.

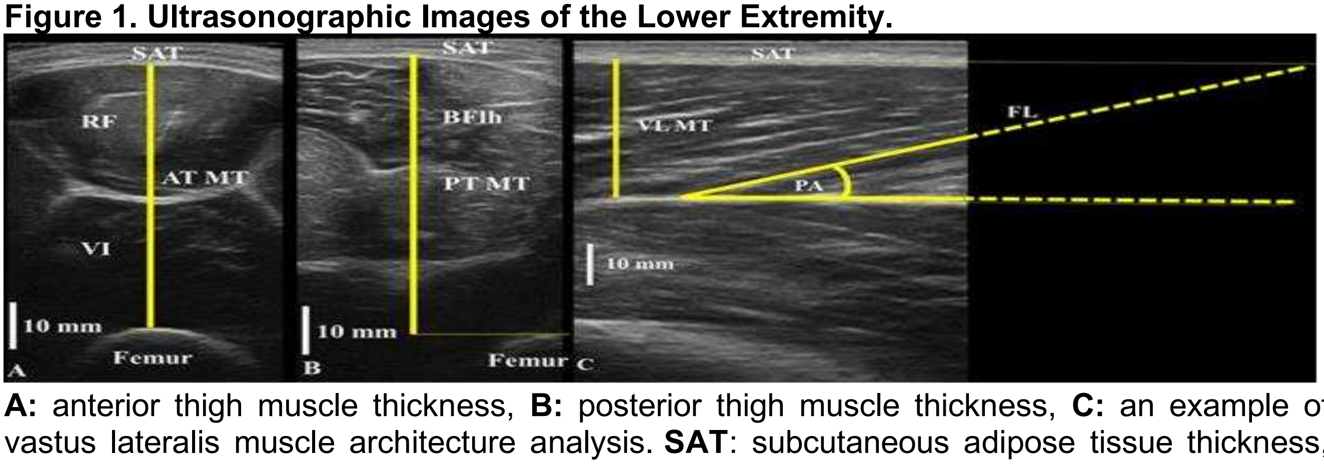
Procedures

The study employed a cross-sectional observational design. The research was carried out in keeping with the Declaration of Helsinki for Human Research. This study was approved by the Human Research Ethics Committee of Thammasat University (Science) (COA No.073/2566). Prior to the examination, all the participants were informed of the purpose and procedures of the study, and then informed consent was obtained. Our study has provided anthropometry data, muscle thickness, pennation angle, fascicle length, knee torque, and sprint performance.

Anthropometry and Muscle Architecture Assessment

The thigh length of the dominant leg was measured while the participants stood in a relaxed position. The measurement was taken as the distance from the greater trochanter of the femur to the articular cleft between the femur and the tibial epicondyle (17). Measurement sites were precisely located and marked. All ultrasonographic assessments were conducted using the Arietta Prologue apparatus (Hitachi, Japan), equipped with a linear array transducer operating at a scanning frequency of 7.5 MHz. Ultrasonographic images were acquired at 50% of the measured thigh length. Muscle thickness was quantified as the distance between the subcutaneous adipose tissue-muscle interface and the muscle-bone interface. To obtain these measurements, a transverse ultrasound probe was positioned on the anterior thigh (quadriceps) and the posterior thigh (hamstrings). Fascicle length was defined as the distance between the intersection of superficial aponeurosis and deep aponeurosis. Fascicle length and pennation angle were measured using a longitudinal ultrasound probe placed along the rectus femoris and biceps femoris. Ultrasonographic images are presented in Figure 1. The images were analyzed with ImageJ 1.52a software (National Institutes of Health, USA). The pennation angle was determined as the angle between the fascicle and the deep aponeurosis. Fascicle length was calculated using the formula (21).

Figure 1. Ultrasonographic Images of the Lower Extremity.



A: anterior thigh muscle thickness, **B:** posterior thigh muscle thickness, **C:** an example of vastus lateralis muscle architecture analysis. **SAT**: subcutaneous adipose tissue thickness, **MT**: muscle thickness, **FL**: fascicle length, **PA**: pennation angle, **AT**: anterior thigh, **PT**: posterior thigh, **RF**: rectus femoris, **VI**: vastus intermediate, **VL**: vastus lateralis, **BFlh**: biceps femoris (long head)

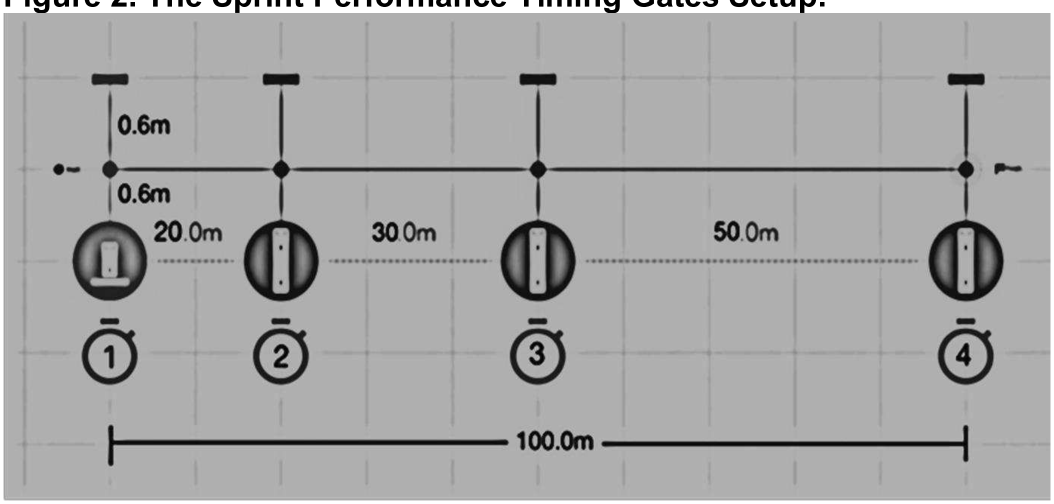
Muscle Strength Assessment

Isokinetic strength was assessed using a Biodex isokinetic dynamometer (Biodex System 4 isokinetic dynamometer, Biodex Medical Systems Inc., Shirley, NY, USA) on the dominant leg at 85° hip flexion and 90° knee flexion in concentric-concentric mode at an angular velocity of 300°/sec. The center of the dynamometer was aligned with the lateral epicondyle of the femur. All the participants were appropriately fixed with belts at the trunk, hip, knee, and leg. Measurements were performed through a range of motion from 90° to 0° of the knee joints, in 2 consecutive sets (5 repetitions/set). Before the strength trials, the participants performed warm-up (cycling) and stretching programs. During the first set, the participants were asked to perform at 50% of maximal effort to familiarize themselves with the task. After a one-minute rest period, the second set was performed with maximal effort. A 20-minute recovery period was allowed before the sprint performance assessment. Peak torque, peak torque per body weight, peak torque angle, time to peak torque, and hamstring and quadriceps ratio were evaluated, then RTD was calculated using the peak torque divided by time to peak torque.

Sprint Performance Assessment

Sprint velocity was recorded using Swift performance timing gates and the SYNCRO application. The timing gates were set up at the 0-meter, 20-meter, 50-meter, and 100-meter marks (Figure 2). Each participant performed a 20-minute warm-up that consisted of jogging, dynamic stretching, and specific stretching. Then, the participants sprinted at maximum speed twice, with a 3-minute rest between each trial. The best time from the 2 trials was used for further statistical analysis.

Figure 2. The Sprint Performance Timing Gates Setup.



Statistical Analyses

Statistical analysis was conducted using the statistical software SPSS (Version 21.0, IBM, SPSS Inc., Chicago, USA). The Shapiro-Wilk test was used to assess the normality of the data distribution before analysis. Non-parametric statistical analysis was used in this study due to the non-normality of some parameters and the small sample size. The median and interquartile range (IQR) were presented for all parameters. Spearman's rank correlation coefficient was used to determine the correlations among variables. The significance level was set at $P < 0.05$.

RESULTS

Table 1 presents the characteristics of the participants, the knee muscle architecture, the knee muscle strength variables, and the sprint performance. The results of correlation are illustrated with the effect size (Cohen's d) in Tables 2-5.

Table 1. Characteristics of Participants, Muscle Architecture, Muscle Strength, and Sprint Performance.

Parameters	Median (IQR)
Participants' Characteristics	
Age (y)	20.00 (4.00)
Height (cm)	180.50 (10.25)
Body mass (kg)	70.40 (9.45)
BMI (kg/m^2)	21.50 (0.88)
Muscle mass (kg)	60.65 (6.45)
Fat mass (kg)	7.25 (4.87)
Muscle Architecture	
AT MT (mm)	52.78 (10.48)
VL PA (deg)	20.00 (4.49)
VL FL (mm)	77.57 (19.73)
PT MT (mm)	60.48 (8.70)
BF PA (deg)	18.40 (10.63)
BF FL (mm)	64.38 (5.79)
Muscle Strength	
KE PTQ/BW (%)	206.35 (41.05)
KE PTQ angle (deg)	62.50 (6.00)
KE PTQ at 30 deg (N-m)	94.05 (26.58)
KE Time to PTQ (msec)	120.00 (17.50)
KE RTD (Nm/msec)	1.22 (0.11)
KF PTQ/BW (%)	136.76 (41.40)
KF PTQ angle (deg)	66.00 (56.00)
KF PTQ at 30 deg (N-m)	70.95 (36.75)
KF Time to PTQ (msec)	255.00 (192.50)
KF RTD (Nm/msec)	0.38 (0.51)
H:Q	65.15 (19.42)
Sprint Velocity	
0-20 m (m/s)	7.20 (0.13)
50-100 m (m/s)	10.19 (0.17)
0-100 m (m/s)	9.40 (0.09)

BMI: body mass index, **AT**: anterior thigh, **PT**: posterior thigh, **VL**: vastus lateralis, **BF**: biceps femoris, **MT**: muscle thickness, **PA**: pennation angle, **FL**: fascicle length, **KE**: knee extension, **KF**: knee flexion, **PTQ/BW**: peak torque/body weight, **RTD**: rate of torque development, **H:Q**; hamstring and quadriceps ratio, **IQR**: interquartile range

No significant correlations were found between all muscle architecture and muscle strength variables (Table 2).

Table 2. Correlation Between Muscle Architecture and Muscle Strength.

	KE PTQ/BW		H:Q ratio	
	r [95% C.I.]	Cohen's d [95% C.I.]	r [95% C.I.]	Cohen's d [95% C.I.]
AT MT	-0.12 [-0.77, 0.65]	-0.24 [-1.64, 1.15]	-0.57 [-0.91, 0.25]	-1.39 [-3.07, 0.30]
VL PA	0.12 [-0.65, 0.77]	0.24 [-1.15, 1.64]	-0.41 [-0.87, 0.44]	-0.90 [-2.42, 0.62]
VL FL	0.07 [-0.68, 0.75]	0.14 [-1.25, 1.53]	0.07 [-0.68, 0.75]	0.14 [-1.25, 1.53]
	KF PTQ/BW		**H:Q ratio**	
	r [95% C.I.]	**Cohen's d [95% C.I.]**	**r [95% C.I.]**	**Cohen's d [95% C.I.]**
PT MT	-0.38 [-0.86, 0.46]	-0.82 [-2.32, 0.68]	-0.33 [-0.85, 0.51]	-0.70 [-2.17, 0.77]
BF PA	0.45 [-0.39, 0.88]	1.01 [-0.54, 2.56]	0.19 [-0.61, 0.80]	0.39 [-1.02, 1.80]
BF FL	-0.07 [-0.75, 0.68]	-0.14 [-1.53, 1.25]	0.02 [-0.71, 0.73]	0.04 [-1.35, 1.43]

All parameters were analyzed by Spearman's rank coefficient, *****: significant correlation at P < 0.05, **AT**: anterior thigh, **PT**: posterior thigh, **VL**: vastus lateralis, **BF**: biceps femoris, **MT**: muscle thickness, **PA**: pennation angle, **FL**: fascicle length, **KE**: knee extension, **KF**: knee flexion, **PTQ/BW**: peak torque/body weight, **H:Q**; hamstring: quadriceps

No significant correlations were found between all muscle architecture and sprint performance variables (Table 3).

Table 3. Correlation Between Muscle Architecture and Sprint Performance.

	Sprint velocity 0-20 m		Sprint velocity 50-100 m		Sprint velocity 0-100 m	
	r [95% C.I.]	Cohen's d [95% C.I.]	*r* [95% C.I.]	Cohen's d [95% C.I.]	*r* [95% C.I.]	Cohen's d [95% C.I.]
AT MT	-0.67 [-0.94,0.10]	-1.81 [-3.67, 0.06]	0.12 [-0.65, 0.77]	0.24 [-1.15, 1.64]	-0.26 [-0.82, 0.56]	-0.54 [-1.97, 0.90]
VL PA	-0.55 [-0.91, 0.28]	-1.32 [-2.98, 0.34]	-0.06 [-0.75, 0.69]	-0.12 [-1.51, 1.27]	-0.29 [-0.83, 0.54]	-0.61 [-2.05, 0.84]
VL FL	-0.45 [-0.88, 0.39]	-1.00 [-2.56, 0.54]	0.54 [-0.29, 0.91]	1.28 [-0.36, 2.93]	0.29 [-0.54, 0.83]	0.61 [-0.84, 2.05]
PT MT	-0.31 [-0.84,0.52]	-0.65 [-2.11, 0.81]	0.20 [-0.60, 0.80]	0.41 [-1.01, 1.82]	-0.17 [-0.79, 0.63]	-0.35 [-1.75, 1.06]
BF PA	0.50 [-0.34,0.90]	1.15 [-0.45, 2.76]	-0.26 [-0.83, 0.56]	-0.54 [-1.97, 0.90]	0.17 [-0.63, 0.79]	0.35 [-1.06, 1.75]
BF FL	-0.45 -0.88, 0.39]	-1.00 [-2.56, 0.54]	0.32 [-0.51, 0.85]	0.68 [-0.79, 2.14]	-0.07 [-0.75, 0.68]	-0.14 [-1.53, 1.25]

All parameters were analyzed by Spearman's rank coefficient, *****: significant correlation at P < 0.05, **AT**: anterior thigh, **PT**: posterior thigh, **VL**: vastus lateralis, **BF**: biceps femoris, **MT**: muscle thickness, **PA**: pennation angle, **FL**: fascicle length, **KE**: knee extension, **KF**: knee flexion

Sprint velocity over 0–100 meters (median = 9.40; IQR = 0.09 m/s) was positively and moderately correlated with knee flexion peak torque normalized to body weight (median = 1.28; IQR = 0.54 %) (r = 0.81, P < 0.05) and the hamstring-to-quadriceps ratio (median = 65.15; IQR = 19.42%) (r = 0.79, P < 0.05). The associations between muscle strength variables and sprint performance are presented in Table 4.

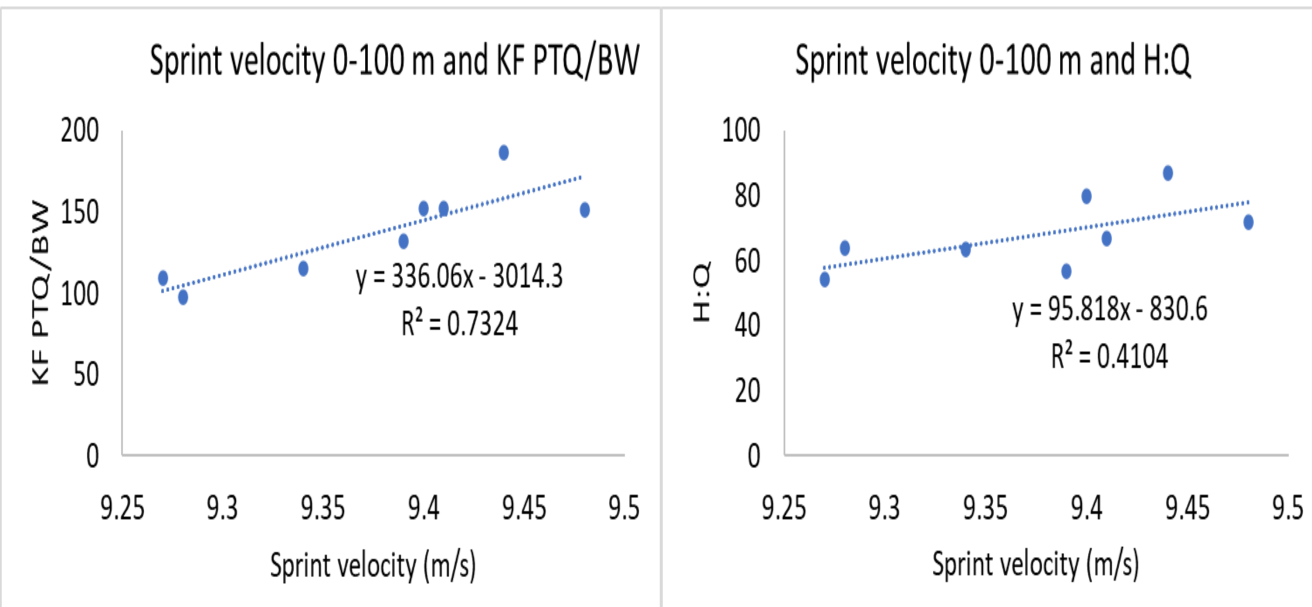
Table 4. Correlation Between Muscle Strength and Sprint Performance.

	Sprint velocity 0-20 m		Sprint velocity 50-100 m		Sprint velocity 0-100 m	
	r [95% C.I.]	Cohen's d [95% C.I.]	r [95% C.I.]	Cohen's d [95% C.I.]	r [95% C.I.]	Cohen's d [95% C.I.]
KE PTQ/BW	0.05 [-0.69, 0.74]	0.10 [-1.29, 1.49]	0.24 [-0.58, 0.82]	0.50 [-0.93, 1.92]	0.50 [-0.34, 0.90]	1.15 [-0.45, 2.76]
KF PTQ/BW	0.14 [-0.64, 0.78]	0.28 [-1.12, 1.68]	0.64 [-0.15, 0.93]	1.67 [-0.14, 3.47]	**0.81* [0.22, 0.97]**	2.76 [0.40, 5.13]
H:Q	0.41 [-0.44, 0.87]	0.90 [-0.62, 2.42]	0.56 [-0.26, 0.91]	1.35 [-0.32, 3.02]	**0.79* [0.16, 0.96]**	2.58 [0.32, 4.84]

All parameters were analyzed by Spearman's rank coefficient, *: significant correlation at $P < 0.05$, **PTQ/BW**: peak torque/body weight, **H:Q**; hamstring:quadriceps

The scatter plots illustrate the relationships between sprint velocity, knee flexion peak torque normalized to body weight, and the H:Q ratio (Figure 3).

Figure 3. The Relationships Between Sprint Velocity, Knee Flexion Peak Torque Normalized to Body Weight, and H:Q.



KF: knee flexion, **PTQ/BW**: peak torque per body weight, **H:Q**; hamstring and quadriceps ratio

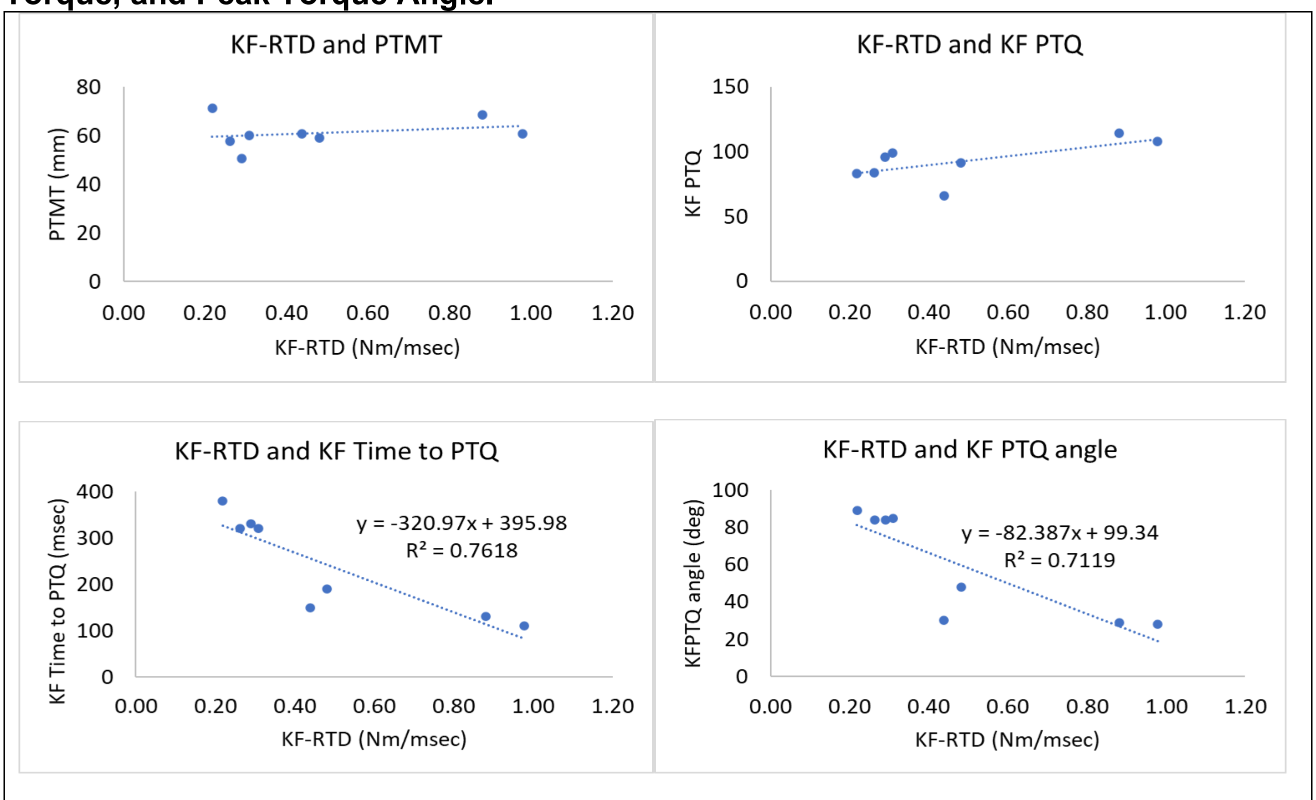
The relationships between RTD and muscle thickness, peak torque, time to peak torque, and peak torque angle are presented in Table 5. Significant positive correlations were observed between RTD and anterior thigh muscle thickness ($r = 0.71$, $P < 0.05$) and between RTD and peak torque in knee extension ($r = 0.81$, $P < 0.05$). In contrast, RTD was negatively correlated with peak torque angle in knee flexion. Additionally, relative RTD was significantly and negatively correlated with time to peak torque in both knee extension and knee flexion. Scatter plots with corresponding linear regression equations are shown in Figure 4.

Table 5. Correlation Between Muscle Characteristics/Strength Variables and Rate of Torque Development.

Parameters	KE RTD	
	r	Cohen's d [95% C.I.]
AT MT (mm)	**0.71* [-0.01, 0.95]**	2.02 [0.05, 3.98]
KE PTQ	**0.81* [0.22, 0.97]**	2.76 [0.40, 5.13]
KE Time to PTQ (msec)	**-0.81* [-0.97, -0.21]**	-2.76 [-5.13, -0.40]
KE PTQ angle (deg)	0.62 [-0.18, 0.93]	1.58 [-0.19, 3.45]
Parameters	**KF RTD**	
	r	Cohen's d [95% C.I.]
PT MT (mm)	0.21 [-0.60, 0.81]	0.43 [-0.99, 1.85]
KF PTQ	0.62 [-0.18, 0.93]	1.58 [-0.19, 3.45]
KF Time to PTQ (msec)	**-0.93** [-0.99, -0.66]**	-5.06 [-8.83, -1.29]
KF PTQ angle (deg)	**-0.90** [-0.98, -0.51]**	-5.06 [-8.83, -1.29]

All parameters were analyzed by Spearman's rank coefficient, *: significant correlation at $P < 0.05$, **AT**: anterior thigh, **PT**: posterior thigh, **MT**: muscle thickness, **KE**: knee extension, **KF**: knee flexion, **PTQ**: peak torque

Figure 4. The Relationship of RTD with Muscle Thickness, Peak Torque, Time to Peak Torque, and Peak Torque Angle.



AT: anterior thigh, **PT**: posterior thigh, **MT**: muscle thickness, **KE**: knee extension, **KF**: knee flexion, **PTQ**: peak torque, **RTD**: rate of torque development

DISCUSSION

This study presents novel evidence linking knee muscle characteristics, including muscle architecture and its strength characteristics, to sprint performance in sub-elite male 100-meter sprinters. The study investigates both morphological and physiological aspects of knee muscles and their influence on sprinting. Morphological characteristics were assessed through measurements of muscle thickness, pennation angle, and fascicle length. Physiological aspects focused on the fast-velocity isokinetic strength of the knee muscles, specifically at an angular velocity of 300°/sec, which is relevant to sprinting movements. The study included participants based on their personal best 100-m sprint times, with sprint performance analyzed across different phases: 0-20 meters, 50-100 meters, and 0-100 meters (ranged 10.55-10.79 sec).

Correlation Between Knee Muscle Architecture and Muscle Function (Strength and Sprint Performance)

This study found no significant correlation between knee muscle architecture and knee muscle strength variables. This finding agrees with a previous study (20), which also reported no relationships between muscle size and muscle function, including fast-velocity strength and sprint time. However, the related study demonstrated the effect of muscle size on torque-producing capacity, both in absolute and relative terms (4). Muscle architecture parameters, such as fascicle length and pennation angle are proposed as predictors of strength (38). An increase in muscle thickness may correspond with an increase in fiber pennation angles (6,22), although the pennation angle may also be influenced by limb length and height as a function of age (6). Sprinting is a functional significance of explosive strength. The type of strength assessment should be considered. There was likely a weak association between the pennation angle and late-phase explosive voluntary torque, but no relationship between fascicle length and explosive strength was found (26). Additionally, Blazevich et al. reported that the fascicle length of the quadriceps femoris plays a role in determining fast-velocity isokinetic strength, though this study was conducted with untrained individuals (8).

Previous research suggests that although muscle size contributes to muscle strength, knee extensor strength may be associated with sprint performance independently of quadriceps femoris muscularity (20). Thus, the athlete’s competitive level may also influence this relationship. In the present study, however, we observed a moderate positive correlation between anterior thigh muscle thickness (ATMT) and knee extensor RTD. The factors influencing muscle strength suggest muscle fiber type and training patterns. Power athletes, including weightlifters and sprinters, typically exhibit a higher proportion of type II muscle fibers (fast-twitch), which are larger, contract more rapidly, and are more prone to fatigue (36). Sprinters often engage in plyometric training, which can increase the proportion of type II fibers compared to endurance athletes or untrained individuals (25,42). However, sprinters generally have a lower proportion of type IIx fibers (fast glycolytic fibers) compared to bodybuilders (42). In terms of muscularity, quadriceps femoris, and hamstrings are considered the most important muscles for sprinting performance (29). Hori et al. highlighted the knee extensor muscles as a major contributor to accelerating the body’s center of mass and increasing peak vertical ground reaction force. Additionally, sprinters tended to have a higher composition of fast-twitch fibers compared to non-sprinters (20). The hamstrings, particularly, play a crucial role in producing horizontal ground reaction force, which is essential for sprint acceleration (30). Muscle fiber composition in the biceps femoris has been reported as 47% slow-twitch, 36% intermediate-twitch, and 17% fast-twitch (16). Muscle fiber type may play a role in morphological and physiological characteristic improvements, but these characteristics are also shaped by specific training strategies (28,34,37). Quadriceps femoris size may be an important factor to consider for enhancing RTD.

As to linking muscle architecture to sprint performance in this study, there were no significant relationships found between muscle morphological variables and sprint performance. This finding agrees with previous studies (20,29) that also reported no correlation between the size of the quadriceps femoris and sprint performance, which is likely due to the multifactorial nature of running ability (20,29). Conversely, some studies reported a positive correlation between sprint performance and both fascicle length (2) and pennation angle (19) in female sprinters. Previous studies discussed the impact of biological sex on sports performance, highlighting sex differences in skeletal muscle fiber types, muscle strength (33), muscle size, and sprint performance (32). Notably, top male sprinters have been shown to have significantly lower ectomorphy compared to those in the lowest tertile (5). These muscle characteristics are important considerations in regards to improve muscle strength and sprint performance. Our findings could emphasize that the knee muscle morphology and muscle architecture did not relate to fast-velocity isokinetic strength or sprint performance in the sub-elite male sprinters. However, it may be that quadriceps femoris thickness relates to RTD through underlying biomechanical and physiological mechanisms.

Correlation Between Muscle Strength, the Related Variables, and Sprint Performance

Our findings supported that fast-velocity knee muscle strength may relate to sprint performance as a previous study has indicated (20). However, some studies have reported the relationship between knee extensor strength (the range of angular velocity: 150-240 °/sec) and sprint performance (14,20). This study found a positive correlation between knee flexor peak torque at an angular velocity of 300°/sec and sprint velocity, as well as between H:Q and sprint velocity. These values may approximate the angular velocities of the thigh segment reported during the swing phase, which ranges from 500 to 800°/sec in sprinters running at speeds of at least 10.50 m/s (12,40). This correlation may be attributed to the involvement of the hamstring from the latter half of the swing phase to the early half of the stance phase for generating horizontal ground reaction force to accelerate forward running (3,18,30,31,41). An increase in knee flexor strength would affect the higher H:Q, the sub-elite participants in the present study exhibited ratios ranging from 56% - 79% that may be an important key to knee muscle balance for sprinters. Higher knee flexor strength and H:Q may relate to sprint performance.

Although muscle strength is frequently assessed as peak torque during isometric, isokinetic, or isotonic muscle contractions; these assessments do not account for speed of contraction. The evaluation of the rate of torque development during rapid contractions could describe the explosive strength of athletes. In knee extension isokinetic strength, RTD was associated with its peak torque and time to peak torque. While RTD in knee flexion isokinetic strength correlated with time to peak torque and the angle of peak torque. Previous research has shown that the ability to generate high-velocity torque partly depends on the capacity to rapidly increase torque during the early phase of contraction, indicating a role for underlying RTD determinants (9). In this study, a shorter time to peak torque was a key factor associated with higher RTD in both knee extension and knee flexion. Additionally, knee extensors demonstrated that peak torque was related to RTD, which is consistent with the observed correlation between muscle thickness and RTD. However, these relationships were not evident in knee flexion. Overall, RTD appears to be primarily determined by the ability to achieve high voluntary activation during the initial 50–75 ms of an explosive contraction (27).

While this study employed an isokinetic concentric–concentric mode for strength testing and used peak torque and time to peak torque to calculate RTD, the time required to reach peak torque exceeded the early contraction window of 50–75 ms. The rate of torque development is not yet a standardized measure and remains challenging to assess with high validity and reliability. A protocol that specifies joint angles, verbal instructions, or how to define and use time periods is also unclear (27,35). These variations may have influenced the correlations observed between RTD and the related isokinetic variables.

Limitations in this Study

This study has several limitations that should be acknowledged. First, the sample size was relatively small, particularly given the strict inclusion criteria for Thai sub-elite male 100-meter sprinters, which may have affected statistical power and the generalizability of the findings. Sub-elite status was defined as a season's best of 10.35–11.50 sec for the 100 m, or an equivalent 60-m/200-m performance based on the International Association of Athletics Federations (IAAF) points (29). Recruitment of competitive-level sprinters is inherently challenging due to constrained training schedules, competition demands, and limited availability for laboratory testing. Consequently, similar studies examining muscle morphology in elite or sub-elite sprinters often rely on small sample sizes due to these practical limitations (23,29). Nevertheless, effect sizes (Cohen's d) were provided to support the interpretation of the results. Therefore, the findings should be interpreted with caution, and future studies with larger cohorts is recommended.

Second, this study assessed muscle strength at a single high angular velocity (300°/sec) to reflect the rapid contraction demands of sprinting. However, isokinetic testing at 300°/ sec may not fully capture the neuromuscular requirements of sprinting, particularly given the influence of different contraction modes such as eccentric actions. Moreover, the use of multiple testing velocities such as 60°, 180°, and 300°/sec would have provided a more comprehensive characterization of the force–velocity relationship.

Third, certain factors such as pre-test fatigue, nutritional status, and recent training intensity were not fully controlled and may have contributed to variability in the results. Although the participants were instructed to avoid strenuous activity for 24 hours before testing and to maintain their habitual dietary and recovery routines, these measures may not have completely mitigated the influence of these variables. Future studies should implement tighter control or monitoring of these factors to reduce potential confounding effects.

Also, this study did not incorporate biomechanical and neuromuscular data during the 100-m sprint, which could have provided further insights into the knee muscle characteristics and their relationship to sprint performance.

CONCLUSIONS

Knee muscle architecture showed no direct associations with muscle strength or sprint performance in sub-elite 100-m sprinters. Sprint performance was instead associated with greater normalized knee flexor strength and a higher hamstring-to-quadriceps ratio. Knee flexion RTD was related to faster torque production and a lower peak torque angle, while knee extension RTD was associated with faster and stronger torque generation and greater anterior thigh thickness. These findings highlight the potential relevance of rapid force-production capacities to sprint performance, warranting further investigation.

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Obstacle Course Racing: Uncovering the Demographics, Training Practices, and Injury Risks of the Sport

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ABSTRACT

Obstacle course racing (OCR) is a popular sport that combines endurance, strength, and athleticism. Despite its popularity, there is limited research on the demographic characteristics, training practices, and injury patterns of OCR athletes. A survey was completed by 176 OCR athletes aged 18–67 years who participated in at least 1 OCR event within the past 12 months. The participants were recruited through nonrandom sampling methods, including social media promotion and snowball sampling. This survey was open for 1 month during July of 2024 and collected data on demographics, training history, and injury patterns. Descriptives and inferential statistics were used to analyze the responses. Among the 176 participants, 44.9% reported sustaining an injury during an OCR event in the past 12 months. The most common injured body parts were the foot and ankle (31.6%), followed by the shoulder (21.5%) and knee (17.7%). Of those injured, 17.7% sought on-site medical attention, and 60.8% pursued further medical evaluation post-event. The participants who trained more than 8 hours/week (OR = 5.4, 95% CI: 1.10–52.94, P = 0.036), participated in competitive leagues (OR = 2.64, 95% CI: 1.36–5.22, P = 0.004), and completed over 75% of their training on trails compared to those with no trail training (OR = 3.07, 95% CI: 1.14–8.61, P = 0.026) have significantly higher odds of injury. This study highlights the demanding nature of OCR and its associated injury risk. The findings suggest that injuries are often influenced by race-specific factors, such as obstacle difficulty and participant preparedness. Improved safety protocols, targeted training programs, and enhanced medical support at events could mitigate risks and enhance athlete safety. Future longitudinal studies are warranted to further investigate causative factors and injury prevention strategies in OCR. Understanding the training patterns and injury risk factors in OCR athletes can help sports medicine clinicians develop targeted prevention strategies, improve the event safety protocols, and guide return-to-play decisions.

Key Terms: Athletic Injuries; Risk Factors; Sports Medicine

INTRODUCTION

Obstacle course racing (OCR) is a popular recreational race event that combines elements of endurance, strength, and athleticism. OCR is a mass participation event held at venues with varying terrain, such as ski resorts, parks, or sports stadiums. The event itself combines traveling on foot through a marked course with unique obstacles along the way. The course can frequently involve maneuvering through highly technical terrain. Obstacles include challenges like traversing monkey bars, carrying heavy objects, climbing over walls, crawling under barbed wire, or throwing objects for accuracy. OCR events can have up to 30,000 participants in a single weekend. The participant skill levels can vary widely from professional athletes to untrained non-exercisers. Race distances typically range from 3 km to 50 km, though races as short as 100 m and as long as 100+ miles do exist.

There are more than 2,500 yearly OCR events worldwide put on by multiple race organizations, including Spartan Race, Savage Race, Tough Mudder, and others (12). There were an estimated 500,000 OCR participants in the US alone in 2017 (8). The 2024 Spartan Racer schedule includes over 40 destinations across the United States (10). OCR is extremely popular overseas as well. In 2020, Spartan Race had scheduled over 250 events in 40 countries (13). In recent years, there has been a push within the OCR community to make OCR an Olympic sport.

The popularity of OCR has expanded into the general fitness community. OCR gyms and training groups have become popular across the globe and give athletes opportunities to practice techniques on obstacles similar to those found on the race course.

Despite being such a popular sport, the medical literature regarding injuries in OCR is sparse. While injuries such as hypothermia, infections, electric shock, and heart attack have been documented, most of the injuries are musculoskeletal in nature (3,15). Similarly, a 2018 study from Canada performed longitudinal analysis of OCR injuries from 2015-2017 for Spartan Race that found an injury rate of 2.4% as measured by athletes seeking on-site medical attention at the race venue (9). Hawley et al. (4) reviewed a series of OCR events in Canada during a 3-month period and reported 1.2% of competitors sought on-site medical care, with 2% of those athletes requiring transfer to hospital for higher level of care. A 2019 study surveyed Polish OCR athletes and found a self-reported annual injury rate to be 27. Jo4% (7). To the best of our knowledge, no further self-reported injury rates for OCR athletes have been published in the literature. Due to the large discrepancy between rates of athletes seeking on-site medical care versus self-reported injury risk, further research is warranted to investigate this difference. It is important to identify potential risk factors that can pose a risk to injuring participants to improve safety measures that improve the overall safety of OCR events and to protect the health of the athletes.

In this exploratory study, we quantify self-reported injury patterns in OCR athletes, and explore how training history and demographic characteristics relate to injury experience.

METHODS

Subjects

This study was designed to be inclusive by recruiting across diverse OCR community platforms. No restrictions on age (beyond ≥18), sex, race/ethnicity, or geographic region were imposed, and all eligible participants were invited.

Procedures

Our team administered surveys to potential OCR participants through social media. We conducted survey recruitment by targeting social media groups and pages related to obstacle course racing. Most of our targeted social media pages had screening protocols that required followers of the group to have completed or signed up for an OCR event. These social media groups were primarily based in the United States. Our team also employed snowball sampling by encouraging participants to share the survey with others who have participated in OCR. The survey was open for 1 month during July of 2024 and took between 2-10 minutes to complete. The survey was modeled after a validated survey conducted by Lyszczarz et al. (7) and adjusted for some limitations mentioned in survey design. The questionnaire consisted of original questions relating to demographics, injury history, racing history, and training history (Supplemental Figure 1). We referred to previously published survey-based projects for OCR and long-distance running when forming our questionnaire.

As was done in the study by Lyszczarz et al. (7) injury was defined in our study as "pain or damage the body sustained during participation in obstacle course races, having a negative impact (restriction on or stoppage) on training or participation in sports competitions." This definition was provided to participants when asked about injury history in the questionnaire. This definition is taken from the running-related injury definition (14). Our ***inclusion criteria*** were adults aged 18-70 who participated in at least one OCR event in their lifetime. The ***exclusion criteria*** included those who reported not participating in an OCR event.

The study data were collected via an online survey using the Google Forms platform. The study participants gave their informed consent by completing the survey after being informed of the purpose of the research. The protocol received IRB approval from our institution. No patient identifying data or personal information was obtained. All responses were completely anonymous and stored confidentially on an institutional computer.

Statistical Analyses

All statistical analyses were conducted using IBM SPSS Statistics Version 30.0.0.0 in Loma Linda, California, with a two-sided alpha level of 0.05. Univariate descriptive statistics were calculated to summarize the characteristics of the study sample. To examine predictors of injury among the obstacle course racing participants, we used Firth logistic regression analysis, a penalized likelihood approach designed to reduce small-sample bias in maximum likelihood estimation.

RESULTS

In total, 184 surveys were collected during the 1-month period. Eight were excluded for self-reporting that they had not completed an OCR event. Estimating the proportion of the target population surveyed was not feasible since the questionnaires were distributed via online groups and social media pages associated with OCR. Overall, 176 surveys met our ***inclusion criteria*** and were included in the analysis.

From the 176 included participants, there were 85 females (48.3%) and 91 males (51.7%). The mean age was 40.38 (SD = 10.85 years) with a range of 20-67. The mean height was 1.71 m (SD = 0.11 m). Most participants (97, 55.1%) had a BMI range within 18.5-24.99, followed by 58 (33.0%) with 25-29.99, 10 athletes (5.7%) with 30-34.99, 6 athletes with (3.4%) 35-39.99, 3 athletes with 40+ (1.7%), and 2 athletes with BMI <18.5 (1.1%) (Table 1).

Table 1. Participant Demographics.

Variable	Category	n (%)	Mean ± SD	Range
Total Participants	176 (100%)			
Age			40.38 ±10.85	20-67
Gender	Male	91 (51.7%)		
	Female	85 (48.3%)		
Height (m)			1.71 ± 0.11	1-2
BMI	Underweight (<18.5)	2 (1.1%)		
	Normal weight (18.5 to <25)	97 (55.1%)		
	Overweight (25 to <30)	58 (33.0%)		
	Obese: Class I (30 to <35)	10 (5.7%)		
	Obese: Class II (35 to <40)	6 (3.4%)		
	Obese: Class III (>= 40)	3 (1.7%)		

Across the participants' lifetimes, 112 participants (63.6%) had participated in more than 20 OCR events, 32 (18.2%) had participated between 11-20 OCR events, 21 (11.9%) had participated between 4-10 OCR events, and 11 (6.3%) had participated in 1-3 OCR events. In the past 12 months, 32 participants (18.2%) had competed in 1 or 2 races, 59 (33.5%) had participated in 3-5 races, 39 (22.2%) had participated in 6-9 races, and 46 (26.1%) had participated in 10+ races. Seventy-seven (43.8%) participants reported competing in primarily an open/non-competitive heat, 66 (37.5%) in an age-group or competitive heat, and 33 (18.8%) had competed in an elite/professional heat (Table 2).

Table 2. OCR Participation History.

Category	Category	n (%)
Lifetime OCR Participation	Lifetime OCR Participation >20	112 (63.6%)
	Lifetime OCR Participation 11-20	32 (18.2%)
	Lifetime OCR Participation 4-10	21 (11.9%)
	Lifetime OCR Participation 1-3	11 (6.3%)
OCR Participation (Past 12 Months)	1 or 2 Races	32 (18.2%)
	3-5 Races	59 (33.5%)
	6-9 Races	39 (22.2%)
	10+ Races	46 (26.1%)
Level of League Competitiveness	Open/Non-Competitive	77 (43.8%)
	Age-Group Competitive	66 (37.5%)
	Elite/Professional	33 (18.8%)

In a 12-month timespan, 76 participants (43.2%) perform training runs 3-4 days a week, followed by 49 participants (27.8%) training 1-2 days per week, 37 (21.0%) 5-7 days per week, and 14 (8%) trained runs less than 1 day a week. Regarding the percentage of training runs performed on trails (vs. road, treadmill, gravel paths, etc.), 31 participants (17.6%) reported not training on trails, 63 (35.8%) up to 25% of training on trail runs, 34 (19.3%) between 25-50% of training on trail runs, 15 (8.5%) between 50-75%, and 33 (18.8%) over 75% (Table 3).

Table 3. Training Patterns.

Category	Category	n (%)
Running Training (days/week)	<1 Day/Week	14 (8.0%)
	1-2 Days/Week	49 (27.8%)
	3-4 Days/Week	76 (43.2%)
	5-7 Days/Week	37 (21.0%)

Trail Running (% of total runs)	0% of training on trail runs	31 (17.6%)
	25% of training on trail runs	63 (35.8%)
	25-50% of training on trail runs	34 (19.3%)
	50-75% of training on trail runs	15 (8.5%)
	>75% of training on trail runs	33 (18.8%)
Strength Training (days/week)	<1 Day/Week	3 (1.7%)
	1-2 Days/Week	56 (31.8%)
	3-4 Days/Week	84 (47.7%)
	5-7 Days/Week	33 (18.8%)
Non-Running Cardio Training (days/week)	<1 Day/Week	32 (18.2%)
	1-2 Days/Week	99 (56.3%)
	3-4 Days/Week	35 (19.9%)
	5-7 Days/Week	10 (5.7%)
Obstacle-Specific Training (days/week)	<1 Day/Week	94 (53.4%)
	1-2 Days/Week	66 (37.5%)
	3-4 Days/Week	15 (8.5%)
	5-7 Days/Week	1 (0.6%)
Total Weekly Training Duration (hours/week)	1-3 Hours/Week	8 (4.5%)
	3-5 Hours/Week	26 (14.8%)
	5-8 Hours/Week	65 (36.9%)
	>8 Hours/Week	77 (43.8%)

Within this time frame, 84 participants (47.7%) performed strength training 3-4 days a week, followed by 56 (31.8%) at 1-2 days a week, 33 (18.8%) at 5-7 days a week, and 3

(1.7%) with less than 1 day a week. Responding to average number of days per week performing non-running forms of cardiovascular exercise (cycling, elliptical, swimming, rowing machine, etc.), 99 participants (56.3%) performed 1-2 days a week, 35 (19.9%) 3-4 days a week, 32 (18.2%) less than 1 day a week, and 10 (5.7%) 5-7 days a week (Table 3).

Within 12 months of the race, responding to the average number of days per week performing obstacle-specific training (i.e., rigs, walls, carriers, etc.), 94 participants (53.4%) performed 1-2 days per week, 66 (37.5%) performed less than 1 day a week, 15 (8.5%) performed 3-4 days a week, and 1 (0.6%) performed 5-7 days a week. The average hours per week spent training in total had 77 (43.8%) reported more than 8 hours, 65 (36.9%) reported 5-8 hours, 26 (14.8%) reported 3-5 hours, and 8 (4.5%) reported 1-3 hours. No participants reported less than 1 hour of total training (Table 3).

Seventy-nine of the 176 surveyed participants (44.9%) reported sustaining an injury during an obstacle course race in the past 12 months. Among the 79 individuals injured in the past year, 43 (54.4%) sustained the injury while navigating an obstacle, and 36 (45.6%) sustained injuries while running (Table 4).

Table 4. Injury Prevalence and Characteristics During OCR Participation.

Category	Category	n (%)
Injury in OCR (past 12 months)	No injuries reported	97 (55.1%)
	Injuries reported	79 (44.9%)
Mode of Injury	Running between obstacles	36 (45.6%)
	Navigating obstacles	43 (54.4%)
Race Distance during which the Injury was Sustained	Less than 5 miles	12 (15.2%)
	5-9 miles	28 (35.4%)
	9-15 miles	23 (29.1%)
	15-30 miles	10 (12.7%)
	Greater than 30 miles	6 (7.6%)
Cause of Injury, Self-Reported	Aggravation of previous injury	21 (26.6%)
	Other/not listed	14 (17.7%)
	Terrain conditions	14 (17.7%)

	Insufficient physical preparation for race demands	14 (17.7%)
	Difficult obstacles	11 (13.9%)
	Inclement weather	3 (3.8%)
	Unsafe obstacles	2 (2.5%)
Body Location of Injury	Foot and Ankle	25 (31.6%)
	Shoulder/upper arm	17 (21.5%)
	Knee	14 (17.7%)
	Hip/thigh	9 (11.4%)
	Wrist/hand	5 (6.3%)
	Back	3 (3.8%)
	Elbow/forearm	3 (3.8%)
	Shin/lower leg	2 (2.5%)
	other	1 (1.3%)
Sought On-Site Medical Attention	No	65 (82.3%)
	Yes	14 (17.7%)
Sought Additional Medical Evaluation Outside of Event*	No	31 (39.2%)
	Yes	48 (60.8%)
Sought Orthopaedic Evaluation	No	47 (59.5%)
	Yes	32 (40.5%)
Surgical Intervention	Yes	7 (8.6%)
Return to Training Post-Injury	Within 7 days	14 (17.7%)
	1-2 weeks	14 (17.7%)
	2-4 weeks	14 (17.7%)

	1-3 months	23 (29.1%)
	3-6 months	9 (11.4%)
	>6 months	5 (6.3%)

*Additional medical evaluation includes visits to the emergency room, urgent care, or a primary care provider after the event.

As for race distance, 28 participants (35.4%) sustained their injury during a race between 5-9 miles. Race distances of 9-15 miles accounted for 23 (29.1%) injuries. Races shorter than 5 miles accounted for 12 injuries (15.2%). Race distances between 15-30 miles accounted for 10 injuries (12.7%), and races longer than 30 miles accounted for 6 injuries (7.6%) (Table 4).

The most frequently self-reported cause of injury was aggravation of previous injury, with 21 participants (26.6%). Terrain conditions and insufficient physical preparation for race demands were cited by 14 participants (17.7%) each. Difficult obstacles were reported by 11 (13.9%), inclement weather by 3 (3.8%), and unsafe obstacles by 2 (2.5%) participants. Fourteen participants (17.7%) reported "other/not listed" reason for injury (Table 4).

The most frequently injured body part was foot and ankle (25, 31.6%), followed by shoulder/upper arm (17, 21.5%), knee (14, 17.7%), hip/thigh (9, 11.4%), wrist/hand (5, 6.3%), back (3, 3.8%), elbow/forearm (3, 3.8%), shin/lower leg (2, 2.5%), other (1, 1.3%). Sixty-five participants (82.3%) reported not seeking on-site medical attention during the event, while 14 (17.7%) did. Forty-eight participants (60.8%) sought delayed or outside medical evaluation after the event (emergency room, urgent care, primary doctor visit, etc.). Thirty-two participants (40.5%) were eventually evaluated by an orthopedic specialist. Seven athletes (8.6%) had surgery to treat their injury (Table 4).

After injury, 23 individuals (29.1%) returned to training within 1-3 months, 14 (17.7%) within 7 days, 14 (17.7%) between 1-2 weeks, 14 (17.7%) between 2-4 weeks, 9 (11.4%) between 3-6 months, and 5 (6.3%) after 6 months (Table 4).

As mentioned, first logistic regression was used to examine potential predictors of injury among OCR participants (Table 5). No statistically significant associations were found between injury risk and gender, age, height, body mass index (BMI), strength training frequency, obstacle-specific training frequency, lifetime OCR participation, OCR participation within the past 12 months, or running and non-running cardio training frequency (Table 5).

Table 5. Results of Firth Logistic Regression Analyzing Predictors of Injury Among Obstacle Course Racing Participants.

Category	Reference group	Predictor	Odds ratio	95% Confidence Interval		P-value
				Lower bound	Upper bound	
Gender	Female	Male	0.85	0.47	1.53	0.577
Age	[redacted]		1.02	0.99	1.05	0.116
Height			0.34	0.02	5.55	0.451
OCR Participation (Past 12 Months)	1-2 races	3-5 races	1.7	0.7	4.25	0.241
		6-9 races	2.04	0.79	5.45	0.141
		10+ races	2.33	0.94	6.07	0.069
BMI	Underweight (<18.5)	Normal weight (18.5 to <25)	0.9	0.07	11.41	0.931
		Overweight (25 to <30)	0.82	0.06	10.48	0.863
		Obese: Class I (30 to <35)	0.47	0.03	7.37	0.566
		Obese: Class II (35 to <40)	1	0.06	17.65	1
		Obese: Class III (>= 40)	0.14	0	4.43	0.273
Strength Training (days/week)	<1 Day/Week	1-2 Days/Week	0.31	0.03	2.51	0.267
		3-4 Days/Week	0.76	0.07	5.96	0.793

		5-7 Days/Week	0.31	0.03	2.58	0.271
Obstacle-Specific Training (days/week)	<1 Day/Week	1-2 Days/Week	1.14	0.61	2.15	0.681
		3-4 Days/Week	1.53	0.51	4.69	0.445
		5-7 Days/Week	0.45	0	8.76	0.61
Total Weekly Training Duration (hours/week)	1-3 Hours/Week	3-5 Hours/Week	3.71	0.66	38.79	0.143
		5-8 Hours/Week	3.57	0.72	35.26	0.128
		>8 Hours/Week	**5.4**	**1.1**	**52.94**	**0.036**
Lifetime OCR Participation	1-3 OCR	4-10	0.43	0.09	2.08	0.288
		11-20	1.02	0.26	4.24	0.982
		> 20 OCR	1.85	0.56	6.87	0.316
Competition Level	Open/ Non-Competitive	**Age-Group Competitive**	**2.64**	**1.36**	**5.22**	**0.004**
		Elite/Professional	1.21	0.52	2.76	0.654
Running Training (days/week)	<1 Day/Week	1-2 Days/Week	0.77	0.24	2.56	0.66
		3-4 Days/Week	1.45	0.48	4.6	0.511
		5-7 Days/Week	0.9	0.27	3.11	0.866
Trail Running (% of total runs)	0% of training on trail runs	25% trail	1.26	0.53	3.09	0.604
		25-50% trail	0.99	0.36	2.71	0.985
		50-75% trail	2.61	0.77	9.31	0.123

		>75% trail	**3.07**	**1.14**	**8.61**	**0.026**
Non-Running Cardio Training (days/week)	1-3 Hours/Week	3-5 Hours/Week	0.94	0.43	2.09	0.883
		5-8 Hours/Week	1.07	0.41	2.77	0.892
		>8 Hours/Week	0.33	0.06	1.44	0.146

Participants who trained for more than 8 hours per week had significantly higher odds of injury compared to those who trained 1–3 hours weekly (OR = 5.40, 95% CI: 1.10–52.94, P = 0.036). Similarly, those who competed in the age-group competitive league had significantly higher odds of injury compared to non-competitive participants (OR = 2.64, 95% CI: 1.36–5.22, P = 0.004). Training primarily on trails was also associated with greater odds of injury. Specifically, those who completed more than 75% of their running on trails had higher odds of injury than those who did no trail running (OR = 3.07, 95% CI: 1.14–8.61, P = 0.026) (Table 5).

DISCUSSION

Participant Characteristics and Training Practices in Obstacle Course Racing

Our project objective was to better understand injury frequency and risk in obstacle course racing and investigate any correlates to injury. To the best of our knowledge, our research is the largest study to date investigating descriptive statistics among OCR events. We have selected a convenient, nonrandom sample of athletes who have participated in our survey to obtain descriptive and correlational statistics surrounding OCR and observe injury frequency and associations in our sample. Of 184 athletes who filled out the survey, 176 were included. 44.9% of which reported an injury during an OCR event during the past 12 months. We found the descriptive statistics to be important because they allow for the establishment of sample baseline characteristics in a relatively understudied population.

The study's participant pool consisted of nearly equal representation of females and males, which reflects a balanced gender distribution with a mean age of 40 years. The BMI distribution showed that most participants fell within a normal range (18.5–24.99), indicative of a relatively healthy and active population. This aligns with the rigorous physical demands of OCR events. However, it is important to note that in athletic arenas, BMI may not be an accurate representation of physical fitness due to its inability to account for muscle mass. Additionally, there was no correlation between injury rates and BMI.

Training patterns revealed significant dedication among the participants. Over 70% engaged in training runs and around 65% in strength training at least 3-4 times weekly, with nearly half training more than 8 hours per week. Also, a notable percentage (43.8%)

participated in open or non-competitive leagues, while others engaged in competitive and elite-level events. The diversity in training practices underscores the physical preparation the participants undertake, although variability in trail-specific and obstacle-specific training could contribute to injury risks.

Most of the respondents participated in up to 3 races (26.1% for 10+ races, 22.2% for 6-9 races, and 33.5% for 3-5 races). In comparison with Lyszczarz et al. (7) the Polish participants appeared to participate in a higher number of races annually, with an average of 6.6 OCR in 12 months. Ninety-two percent of the participants in the present study ran at least once per week, which is similar to the 88.2% of the respondents in the Lyszczarz et al. (7) study. Similarly, most of our participants engaged in regular strength training sessions, which is similar to the near 80% of athletes who practiced bodyweight and weight-training sessions found by Lyszczarz et al. (7). Forty-seven percent of the participants in the present study performed obstacle-specific training at least 1 time a week, which is similar to 60.8% reported by Lyszczarz et al. (7). The Polish paper found that ground was the most popular running surface (44.4%), followed by asphalt (38.6%) and concrete (5.9%). Our study found that 17.6% did not train on trails, and the majority (35.8%) performed up to 25% of training on trails, and trail-specific training varied widely. While our study and the Lyszczarz et al. study shared some similarities, such as the emphasis on frequent running and strength training, the Polish cohort reported higher race participation and more structured training practices (e.g., group training and trainer use). Injury rates were comparable but with differences in specific associations. Our study identified competitive league participation and intermediate experience as key risk factors, while the Polish study highlighted higher race counts among injured athletes. These differences underscore the need for standardized data collection methods and more cross-population comparisons to deepen the understanding of OCR training and injury dynamics (7).

Injury Prevalence, Patterns, and Associated Risk Factors

Almost half (44.9%) of the participants reported a history of an OCR-related injury during the past year, with a majority occurring while navigating obstacles. Injuries predominantly affected the foot and ankle, followed by the shoulder and knee, which are critical to both running and obstacle completion. The high incidence of injuries related to obstacle navigation suggests that course design and obstacle safety could be areas that OCR companies should investigate to improve athlete safety.

Interestingly, the participants who trained more than 8 hours per week were significantly more likely to report injuries than those who trained only 1–3 hours per week (OR = 5.4, CI: 1.10–52.94, P = 0.036). This aligns with the Lyszczarz et al. (7) study that reported risk of injury increased with more time devoted to training per week. One possible explanation is that high training volumes without adequate recovery may contribute to overuse injuries or cumulative fatigue (2). The correlation between total weekly training duration and injury risk suggests a need for balanced training regimens that incorporate proper rest and recovery.

Participation in competitive leagues was also associated with higher injury rates (OR = 2.64, CI: 1.36–5.22, P = 0.004). This could be due to the increase in training intensity, performance pressure, or a higher willingness to push through early signs of injury (1). Moreover, athletes who performed more than 75% of their training on trail runs were more likely to report injuries compared to those who did no trail running at all (OR = 3.07, CI: 1.14–8.61, P = 0.026). This may be due to the unpredictable terrain and higher biomechanical demands of trail running, which can increase the risk of ankle sprains, falls, or repetitive strain injuries (5). These findings emphasize the need for further research into the role of different training surfaces in injury prevention and performance optimization.

Notably, injuries in our study were not significantly associated with demographic variables such as age, gender, or height, which is a finding that aligns with the results of the Lyszczarz et al. (7) who also reported no significant associations between demographic factors and injury risk. In contrast, our study found no correlation between injury risk and the amount of strength training, obstacle-specific training, running, or non-running cardio training completed by athletes. This contradicts the findings of Lyszczarz et al. (7), which indicated that increased time spent on obstacle training, running, and non-running training was significantly associated with a higher risk of injury. Similarly, we found no significant association between injury risk and lifetime OCR participation. However, Swart et al. (11) reported a statistically significant increase in injury rates among runners who had participated in more than 20 races compared to those who had participated in 4 to 10 races. These discrepancies may be attributed to differences in race type, intensity, or injury definitions across studies, or to cumulative wear and tear in more experienced athletes. Further research is needed to clarify the relationship between training volume, training type, participation history, and injury risk.

Clinical Implications, Limitations, and Future Directions

Most participants did not seek on-site medical attention for their injuries (82.3%), although over half did seek outside medical evaluation post-event. The significant number of injuries needing medical attention emphasizes the need for robust medical support at OCR events. It should be noted that 8.6% of all injured athletes eventually had surgery to address their OCR-related injuries. This, along with almost 50% of the athletes sustaining an injury annually, OCR participation should be considered a clinically relevant risk factor for undergoing orthopedic surgery.

Post-injury recovery varied with most participants returning to training within 3 months. However, the prolonged recovery times for some underline the potential long-term impact of OCR-related injuries, which necessitates preventive strategies and improvement in recovery protocols.

While this paper serves as the largest participation in descriptive and correlational statistics in OCR, there are several limitations that prevent its generalizability. The design of this study is a non-random, cross-sectional survey with recruitment through social media platforms targeting OCR participants. This limits the generalizability of the results, as the sample may not accurately represent the broader population of OCR athletes. As a cross-sectional study, the design precludes the ability to establish causation or calculate injury incidence rates over time. Future prospective studies would be required to determine the attributable risks and long-term outcomes associated with OCR participation.

The study design relied on self-reported data, which is subject to recall and response bias. The participants who had sustained injuries might have been more likely to complete the survey, potentially inflating the reported injury prevalence. Conversely, individuals without injuries may have been less motivated to participate, skewing the sample's injury profile. This should be considered when viewing an approximately 45% injury report of the participants. This is nearly twice as high as the highest previously reported injury rate found in published literature, e.g., the 2019 surveyed Polish OCR athletes and their self-reported annual injury rate was 27.4% (7). Future research would need to follow these athletes longitudinally and become a prospective study, which would allow for the analysis of attributable risks better.

This study provides a detailed overview of the demographics, training practices, and injury patterns of obstacle course racing (OCR) athletes, thus contributing valuable data to a relatively understudied area of sports medicine. With nearly half of the participants reporting a history of OCR-related injuries in the past year, the findings underscore the physically demanding nature of the sport. Notably, injuries were most frequently sustained during obstacle navigation and were commonly attributed to pre-existing conditions and inadequate preparation. This highlights the importance of tailored training regimens and enhanced safety protocols for both the participants and the event organizers. Self-reported injuries may misrepresent the true burden of OCR-related injuries. A prospective design could address discrepancies in reporting and offer a clearer picture of causative factors and long-term outcomes.

CONCLUSIONS

A significant contribution of this study is its focus on OCR athlete demographics and behaviors, which remain sparse in the scientific literature. The findings provide a foundational understanding of this popular sport, shedding light on training patterns and injury trends that can guide future research and intervention strategies. As OCR continues to flourish, longitudinal research and data-driven safety strategies will be essential in minimizing injuries and supporting the sustainable development of this unique and demanding sport.

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