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Can Body Roundness Index Be Used to Measure and Predict Changes in Overweight and Obese Men and Women After Behavioral Weight Loss Programs?

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ABSTRACT

Darby LA, Keylock T, Choe J-P, Kang M, Berger BG, Carels RA. Can Body Roundness Index Be Used to Measure and Predict Changes in Overweight and Obese Men and Women After Behavioral Weight Loss Programs? Body Roundness Index (BRI) was introduced to quantify body shape regardless of body weight. Anthropometric indexes such as BRI may overcome the limitations of other single body measures or ratios used to indicate level of obesity, such as Body Mass Index (BMI). BRI includes waist circumference (WC) and height to determine the degree of eccentricity of the body; greater BRIs represent “rounder” individuals. The objectives of this study were to determine: (a) whether BRI represented other anthropometrics after the completion of Behavioral Weight Loss Programs (BWLPs); (b) whether BRI could predict success in BWLPs; and (c) whether the results vary due to sex. Data from four previous BWLPs were combined to investigate changes after weight loss for the overweight/obese participants: (Men, n = 31; Women, n = 96). ANOVAs (Time by Sex), regressions, and difference scores (Δ) were calculated for BRI, Body Weight, Percentage Body Fat (%BF), and other variables. All anthropometric variables were significantly different pre- to post-BWLPs except for waist-to-hip ratios (WHR) for both sexes and hip circumference (HC) for men. Both BRI and %BF were less post-BWLPs ($P < .001$); BRI decreased Pre: 5.76 ± 1.99 to Post: 5.37 ± 1.97. A significant main effect of Sex on BRI was observed ($P = .01$) with both the women ($P < .001$) and the men ($P = .004$) with significant decreases in BRI over time. ΔBRI was significantly related to the Δ%BF ($R = .268$; $P = .002$). ΔBRI for the women and the men were significantly related to Δ%BF ($R = .242$; $P = .018$; $R = .366$; $P = .043$, respectively). PreBRI was significantly related to Δ%BF, regardless of sex ($R = .198$; $P = .026$). However, this relationship was significant for the women ($R = .264$; $P = .010$), but not for the men ($R = .081$; $P = .665$). BRI was also representative of other anthropometric measures typically used to monitor BWLP changes over time with the exception of WHR and HC in the men.

Key Words: Behavioral Weight Loss Programs, Body Roundness Index, Sex Differences

INTRODUCTION

Behavioral weight loss programs (BWLPs) are conducted to help adults lose body weight to improve health and reduce the risk of various diseases (4). Carels and colleagues (5-8) have reported changes in body weight, body composition, psychological inventories, and anthropometric measures when combining the LEARN Program (4) with other psychological interventions. Before, during and after BWLPs, numerous anthropometric measures (single variables), and adiposity or obesity indexes (equations combining two or more anthropometric measures) have been employed to describe the shape and size of the human body, identify obesity, and monitor body weight changes. Examples include Body Mass Index (BMI), waist circumference (WC), hip circumference (HC), percentage body fat (% BF), abdominal depth or sagittal abdominal diameter (SAD), visceral abdominal tissue (VAT) and Body Roundness Index (BRI) (10,12,22).

Thomas et al. (30) introduced the Body Roundness Index (BRI) as a newer adiposity index which correlated with visceral adipose tissue and % BF. This index uses height and WC to predict body shape with leaner individuals having a narrower body shape and lower BRI than obese individuals with a rounder shape and greater BRI. BRI represents body eccentricity, the degree of circularity, in a range from 1-20 with lower values representing narrower body shape. Researchers have reported that an increase in BRI increases a variety of health risks: cardiovascular disease (CVD) (18), all-cause mortality (29,32), cardiometabolic abnormalities (31), metabolic syndrome (28), diabetes (9,24), hypertension (2), and other conditions or diseases (15,22).

As an adiposity index, Body Mass Index [BMI = BW (kg)/HT (meters^2)] has been commonly used to rate overweight and obesity but has been reported to have limited sensitivity in representing body tissue changes after weight loss because it does not take into account changes in body composition, fat mass or lean body mass (11,15). Thus, Schweitzer (27) suggested that BRI might be used instead of BMI in future studies.

A few researchers (14,20,25) have used the relatively new BRI in BWLPs to determine if BRI is sensitive enough to monitor changes or correlate with changes in body weight and other anthropometric measures after BWLPs. Whether an anthropometric index such as BRI that combines two anthropometric measures (WC, HT) into the single index, BRI, can represent success in BWLPs such as changes in other anthropometric measures or adiposity indexes needs further study.

Therefore, the purposes of this study were to determine: (a) whether BRI represents body weight and body composition changes after completion of BWLPs similarly to other commonly employed anthropometric measures; (b) whether BRI could represent and predict success in BWLPs such as changes in other anthropometric measures; and (c) whether the results vary due to the sex of the participants. If BRI can be used to monitor clients, then programs may cost effectively and accurately monitor clients' changes during and after BWLPs.

METHODS

Subjects

The participants were overweight and obese men and women [N = 127 (Men, n = 31; Women, n = 96)] who volunteered for BWLPs. They were measured before and after each BWLP that used the LEARN Program (4) and an additional psychological intervention to promote weight loss.

Procedures

Data from pre- and post-Behavioral Weight Loss Programs (BWLPs) were previously collected and reported from Carels et al. (5-8). These data were combined for this study to examine BRI and anthropometric changes in men and women after BWLPs and thus, is a *post hoc* analysis study.

Procedures for each BWLP study are described in Carels et al. (5-8). Dependent variables employed to assess pre- and post-BWLP programs anthropometrics were: Body Weight (BW; kg), BMI, Body Roundness Index (BRI), Percentage Body Fat (%BF), Waist Circumference (WC; cm), Hip Circumference (HC; cm), Waist to Hip Ratio (WHR = WC/HC); Sagittal Abdominal Diameter (SAD; cm), Visceral Abdominal Tissue (VAT; lbs), and difference scores (Δ) (post-BWLP minus pre-BWLP).

Multiple anthropometrics and indexes were measured and calculated. BRI was calculated using the formula with only height and waist circumference (30). Body weight and height were measured using a physician's scale and stadiometer. Waist and hip circumferences were measured with a Gulick tape and the average of three measurements within 5 mm were used for the final value (1). Percentage body fat was determined from body density using the 3-site skinfold formula for men and for women from Jackson and Pollock (1) with conversion to %BF using the Siri equation (1). SAD was measured and converted to VAT according to the procedures in Parr and Haight (19) and Kvist and colleagues (16).

Statistical Analyses

Two-way ANOVAs (2 × 2: Time × Sex) were used to compare pre- to post-BWLP dependent variables. One-way within and between ANOVAs were calculated for each dependent variable with appropriate *post hoc* tests. Pearson correlations and linear regressions were used to investigate relationships between and among variables. IBM® *SPSS®* Statistics, Version 28.0 (IBM Corp., 2021) and R software Version 4.3.1. were used for statistical analyses. Statistical significance was set *a priori* at $P \leq 0.05$ for all analyses.

Latent Class Analyses (LCA) were calculated for BRI, WC, WHR, BMI and SAD to determine if participants for the entire group or for a women-only group could be described based on similar patterns of obesity-related risk indicators. Latent class models with various numbers of classes were estimated, and each model fit was evaluated using Akaike Information Criterion (AIC), Bayesian Information Criteria (BIC), sample-size adjusted BIC (SABIC), entropy, and log-likelihood. All variables were made binary using the following cut-offs for standard obesity measures: BRI $\geq$ 6.91 (32); WC > 102 cm for men and > 88 cm for women, WHR $\geq$ 1.0 for men and $\geq$ .8 for women, BMI > 30 kg/m^2 (1,12), and suggested cut-offs for SAD > 22 cm for men and > 20 cm for women (26).

RESULTS

BRI Representation of Pre- to Post-Programs Change and Differences by Sex

When pre- to post-BWLPs anthropometric variables for all participants were compared for Time and by Sex (see Table 1), BRI, BW, BMI, WC, and %BF all significantly decreased post-BWLPs. There was a significant main effect for sex with men greater than women for BRI, BW, and WC, and men less than women for %BF (see Table 1). There was no significant difference in mean BMI between men and women. For the other four variables of HC, WHR, SAD, and VAT, there were significant interactions for Time by Sex. There was no significant difference in HC for men ($t = .072$, $P = .422$) post-BWLPs, but a significant decrease in HC for women ($t = 7.67$, $P < .001$). For WHR, men were greater than women, but both did not decrease in WHR post-BWLPs (Men, $t = 1.64$, $P = .056$; Women, $t = .192$, $P = .848$). For SAD, men were greater than women, and men and women both had statistically significant decreases post-BWLPs (SAD: Men, *t* = 4.94, P <.001; Women, *t* = 7.56, P < .001). Results for VAT were similar to the results for SAD (see Table 1).

Table 1. Anthropometric Variables Pre- and Post-BWLPs by Sex.

Variables	Men		Women		Interaction *post hoc* Results
	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ±	
BW (kg)*, **	112.8 ± 26.1	108.7 ± 26.6	91.8 ± 17.0	87.9 ± 16.8	
WC (cm)*,**	112.9 ± 14.7	110. ± 16.0	97.5. ± 12.1	94.4 ± 12.3	
HC (cm)***	114.3 ± 13.1	114.3 ± 12.5	119.1 ± 13.6	115.4 ± 13.5	♂ no Δ; ♀□*
WHR*	.99 ± .09	.96 ± .07	.82 ± .08	.82 ± .07	No Δ ♂ or ♀
BMI (kg/m^2)*	36.2 ± 7.3	34.8 ± 7.3	34.5 ± 6.0	33.0 ± 6.0	
BRI*,**	6.51 ± 2.05	6.18 ± 2.14	5.52 ± 1.91	5.10 ± 1.84	
%BF*,**	28.0 ± 6.5	25.9 ± 6.4	45.2 ± 3.8	42.8 ± 5.26	
SAD (cm)***	28.1 ± 3.5	26.0 ± 3.6	25.2 ± 3.2	23.8 ± 3.3	♂□* >♀□*
VAT (lbs)***	19.4 ± 5.5	16.1 ± 5.6	9.5 ± 2.6	8.47 ± 2.6	♂□* >♀□*

P < 0.05 for ***Time**; ****Sex**; *****Sex × Time Interaction**; ♀ = women; ♂ = men; **Δ** = (Post-Pre); **BW** = Body Weight; **WC** = Waist Circumference; **HC** = Hip Circumference; **WHR** = Waist to Hip Ratio; **BMI** = Body Mass Index; **BRI** = Body Roundness Index, **%BF** = Percentage Body Fat; **SAD** = Sagittal Abdominal Diameter; **VAT** = Visceral Abdominal Tissue.

BRI as a Predictor of Success in BWLPs

Mean ΔBRI (post-BRI minus pre-BRI) was a significant predictor of ΔBW, ΔBMI, Δ%BF, and all other dependent variables shown in Table 2. Thus, BRI changes were similar to other anthropometric measures post-BWLPs. When analyzed by Sex, ΔBRI for women was significantly related to and a predictor of Δ%BF (R = .242; P = .018), and also for men (R = .366; P = .043) (see Table 2). Results of correlation and regression analyses for all participants (regardless of sex) found that PreBRI was significantly related to Δ%BF but not correlated with any other Δ scores for anthropometric measures (See Table 3). However, when analyzed by sex, PreBRI was significantly related to and a predictor of Δ%BF for women (R = .264; P = .010), but not for men (R = .100; P = .592) (see Table 3). PreBRI was not a significant predictor of any other difference score for any anthropometric measure.

Table 2. ΔBRI Scores Correlated with Change Scores for all BWLPs Participants and by Sex.

	ΔBW	ΔWC	ΔHC	ΔWHR	ΔBMI	Δ%BF	ΔSAD	ΔVAT
ΔBRI (N = 127)	.604**	.984**	.472**	.262*	.618*	.268*	.285*	.256*
ΔBRI Women (n = 96)	.582**	.982**	.473**	.582**	.597**	.242*	.218*	.218*
ΔBRI Men (n = 31)	.687**	.992**	.563**	-.166	.690**	.366*	.524*	.524*

*P < .05; ** P < .001; **Δ** = (Post-Pre); **BRI** = Body Roundness Index; **BW** = Body Weight; **WC** = Waist Circumference; **HC** = Hip Circumference; **WHR** = Waist to Hip Ratio; **BMI** = Body Mass Index; **BRI** = Body Roundness Index, **%BF** = Percentage Body Fat; **SAD** = Sagittal Abdominal Diameter; Visceral Abdominal Tissue.

Table 3. PreBRI Correlated with Change (Δ) Scores for all BWLPs Participants and by Sex.

	ΔBW	ΔWC	ΔHC	ΔWHR	ΔBMI	Δ%BF	ΔSAD	ΔVAT
PreBRI (N = 127)	-.048	-.091	.122	.177*	-.053	.198*	-.037	-.142
PreBRI Women (n = 96)	.013	-.154	.050	.178	-.013	.264*	.135	.135
PreBRI Men (n = 31)	-.194	.045	.120	.111	-.181	.081	-.288	-.288

*P < .05; **Δ** = (Post-Pre); **BRI** = Body Roundness Index; **BW** = Body Weight; **WC** = Waist Circumference; **HC** = Hip Circumference; **WHR** = Waist to Hip Ratio; **BMI** = Body Mass Index; **BRI** = Body Roundness Index, **%BF** = Percentage Body Fat; **SAD** = Sagittal Abdominal Diameter (SAD); **VAT** = Visceral Abdominal Tissue.

Latent Class Analyses Findings: Heterogeneous Adiposity Patterns

For the entire dataset, the four-class model was selected based on the lowest BIC and improved model fit compared with models with fewer classes (see Table 4). Results of the LCA for all participants regardless of sex, indicated that the item-response probabilities for the indicators of BRI, BMI, SAD, WC, and WHR suggested distinct profiles across four classes, ranging from a lower-risk group for overweight/obesity, Class 1, with low probabilities across all indicators (see Table 4). Two latent classes, Classes 2 and 3, were characterized by elevated central adiposity indicators such as BRI, SAD, WC, and WHR. Class 4 was characterized by a higher overall body adiposity indicated by high probabilities (>.50) for all of the five selected risk indicators (see Table 4). These results for the entire group indicated there were heterogeneous adiposity patterns within the sample for this study.

Table 4. Latent Class Analysis: The Estimated Probabilities for Men and Women Across the Latent Subgroups.

	Class 1	Class 2	Class 3	Class 4
Class Membership %	**(32%)**	**(6%)**	**(18%)**	**(45%)**
Latent Class Profile	**(BRI/BMI)**	**(WC/WHR)**	**(BRI, BMI, SAD)**	**(ALL)**
BRI	0.18	0.43	1*	1*
BMI	0.37	0	1*	1*
SAD	0.1	0.43	0.63*	0.93*
WC	0.02	0.71*	0	1*
WHR	0	1*	0	0.63*

*Probability values of >.50 indicate greater presence of the risk indicator; **BRI** = Body Roundness Index; **BMI** = Body Mass Index; **SAD** = Sagittal Abdominal Diameter; **WC** = Waist Circumference; **WHR** = Waist to Hip Ratio.

For the female data, the two-class model was selected because it showed the lowest BIC and a clear class structure with higher posterior classification probabilities (see Table 5). No LCA was calculated for the male data because of the small sample size. Results of the LCA analysis for females specified two classes. Item-response probabilities indicated Class 2 had substantially higher probabilities for BRI, WC, BMI, and SAD, which suggested a group characterized by greater abdominal and overall adiposity. Class 1 showed consistently low probabilities across all risk indicators for obesity, perhaps identifying the overweight women in the study (see Table 5).

Table 5. Latent Class Analysis: The Estimated Probabilities for Women Only Across the Latent Subgroups.

	Class 1	Class 2
Class Membership %	**(52%)**	**(48%)**
Latent Class Profile	**(BRI/BMI)**	**(All but WHR)**
BRI	0.32	1*
BMI	0.45	0.98*
SAD	0.11	0.91*
WC	0	0.69*
WHR	0.03	0.28

*Probability values of >.50 indicate greater presence of the risk indicator; **BRI** = Body Roundness Index; **BMI** = Body Mass Index; **SAD** = Sagittal, Abdominal Diameter; **WC** = Waist Circumference; **WHR** = Waist to Hip Ratio.

DISCUSSION

BRI is a newer adiposity index that has not been used often to document success in BWLPs. In the present study, it was shown that ΔBRI post-BWLPs was similar to other anthropometric measures and, therefore, BRI could be used to monitor changes post-BWLPs. ΔBRI was a significant predictor of Δ%BF and most other anthropometric difference (Δ) scores regardless of sex and by sex. In contrast, pre-BRI only predicted Δ%BF for women and not for men. This may reflect post-program differences in fat losses reflected by ΔHC, ΔWC, ΔSAD, and ΔVAT between men and women.

Changes in BRI and Other Anthropometric Measures After Weight Loss Programs

All anthropometric measures and adiposity indexes in the present study decreased significantly after the BWLPs for the entire group except HC for men, WHR for men and women. This is similar to Iłowiecka et al. (14) who reported significant decreases after a 12-month energy-restricted diet for various anthropometric indexes such as BRI, BMI, fat mass index, and visceral adiposity index. In a weight loss study that used a pharmacological intervention, a GIP/GLP-1 receptor agonists, and modifications of other lifestyle factors, Paternò et al. (20) reported men and women enrolled in the 3-month study had significant decreases in BRI from a mean of 9.08 ± 2.70 to 7.44 ± 2.43 (Δ = -1.64), in WC (Δ = -10 cm), and in BW (Δ = -10.8 kg). In the present study, ΔBRI (mean = -.40), ΔWC (mean = -2.9 cm), ΔBW (mean = -3.9 kg) for the entire group (see Table 1) were also significantly different after the BWLPs but are below the mean differences reported by Paternò et al. (20). Similarly, Iłowiecka and colleagues (14) indicated that the mean BRI was reduced from 6.13 ± 1.57 to 5.25 ± 1.41 (Δ = - .88) and mean WC was reduced by about 7 cm after the energy restricted diet with no separation of the group by sex. BRI was representative of body shape changes in the present study and differences to other reports may be attributed to various types and durations of weight loss programs, and differences in initial levels of obesity in the participants.

There were significant differences in other anthropometric measures by sex. As expected, men were significantly heavier, had greater WC and had less %BF than women (12). As Lovejoy, Sainsbury and The Stock Conference 2008 Working Group (17) have indicated, there is a difference in body fat distribution between men and women with men and post-menopausal women accumulating more abdominal fat. Large WC and large WHR are predictive of all-cause mortality and cardiovascular disease while a greater HC is cardioprotective (17). As expected, men in the present investigation had on average greater BW, WC, BRI and SAD. In contrast to men, the women had greater HC and % body fat. Men decreased WC post-BWLP while women decreased both WC and HC reflecting sex differences. Attari et al. (3) also reported that BW loss in women was related to a decrease in WC, HC, and %BF. Another sex difference was that ΔBRI was correlated to Δ%BF for both sexes, but preBRI was only correlated to Δ%BF in women. There was no difference between males and females for BMI and hence, changes post-BWLPs between the sexes could not be distinguished by BMI or by WHR, unlike BRI and the other anthropometric measures in the present study. It is obvious that the sex of the participants should be considered in BWLPs.

Latent Class Analyses

There were four subgroups that had heterogeneous differences in the total group. These differences were based on sex and level of obesity (see Table 4). When the women-only group was analyzed, the number of subgroups was reduced to two groups. Further distinguishing obese individuals in the future by type and level of obesity, and by sex may improve conclusions about weight loss and success in BWLPs.

Obesity Standards for BRI and BMI

Schweitzer (27) has explored the question of whether BRI could someday replace BMI worldwide as an indicator of obesity. As Schweitzer (27) indicated, there are few norms for BRI and assessing WC is not necessarily a standard measurement like height and body weight used to calculate BMI. Pratt et al. (23) reported that BRI was strongly correlated with fat metrics with BMI being weakly correlated. When obese men were defined to be overweight/obese by BMI (>25 kg/m^2) and BRI (>4.92 as obese) and compared to the proportion of men who "truly" were obese from their %body fat measures (>25%), Pratt et al. (23) reported that BRI did a better job than BMI of identifying those men who were truly high in body fat. In the present study, ΔBRI was significantly correlated to Δ%BF and is agreement with results from Pratt et al. (23) for men, women, and the total group.

As shown in the present study each anthropometric measure with the exception of WHR and HC was sufficiently sensitive to denote changes post-BWLPs. Thus, researchers and clinicians may use multiple measures in the future to not just identify the presence of obesity, but to rate the type and level of obesity for an individual. This is validated by the results of the LCA shown in the present study that identified groups with "low risk of overweight and obesity, central obesity, overall obesity" and that represented how fat was distributed in the body. As Schweitzer (27) stated, BMI and BRI were established with different intents, in that BMI is a "population-based measure" and BRI is more of an "individual measure".

The mean BRIs for men was > 6.0 and the mean BRIs for women was > 5.1. This indicates that these individuals were truly overweight and mildly obese and at the "higher end" of the middle quintile BRI range of 4.5 to 5.5 reported by Zhang et al. (32) based on the risk of all-cause mortality. Mean BRI for men approached the highest quintile of risk for all-cause mortality from NHANES data 1999-2018 of a BRI > 6.9 reported by Zhang et al. (32). In the original BRI study using NHANES III data, Thomas et al. (30) matched BRI cut-offs to BMI obesity cut-offs with BMI of δ 30 to < 40 kg/m^2 (obese) equal to a BRI of 6.47 ± 1.18 for men and 6.86 ± .01 for women. A BMI of δ 25 to < 29.9 (overweight) was equal to a BRI of 4.66 ± 0.91 for men and 4.96 ± 1.06 for women. Mean BRI values in the present study were representative of overweight and obese groups. Further cut-offs for defining obesity based on BRI need to be established in future studies.

It should be noted that BRI can vary based on age and population. Pratt et al. (23) reported that BRI was correlated with age regardless of sex and increased about 2 units per decade from adulthood (30-39 yrs of age) to late adulthood; from a mean of about 2.9 for men and 2.2 for women to a mean BRI of ~4.5 for men and 4.0 for women at 70-79 years of age in Irish individuals. In the present study, BRI was not correlated to age and may represent the small range of ages in the present study. Researchers have studied different ethnicities and have reported varied means for Chinese men and women, BRI 3.70 ± 1.22 (9); South Asians, BRI 3.3 ± 1.0 (11); Polish men of 4.9 ± 1.4 and women of 4.5 ± 1.7 (28); individuals of European descent, BRI 4.47-4.84 (13); Americans, data from NHANES studies, 4.9 for men and 4.5 for women (32). Hence, use of BRI calculator established by Thomas et al. (30) at the Pennington Biomedical Research Center, (https://www.pbrc.edu/research-and-faculty/calculators/brc.aspx, that takes into account ethnicity of White, Black and Mexican Americans, HC, and age may be used to mitigate these confounding variables. Future research may further identify representative BRIs for various samples of the worldwide population.

Limitations in this Study

The sample used in the present study included overweight (BMI $\geq$25 kg/m^2) as well as obese ($\geq$ 30 kg/m^2) individuals. In addition, the duration of each BWLP was different and varied between 3-7.5 months (5-8), however, mean BW significantly decreased in each of the previous BWLP studies.

In the present study, the original BRI formula with only WC and height was used to determine BRI. This is cost effective and avoids the time and expertise needed to measure multiple anthropometric measures (30). However, the online calculator of BRI includes WC along with HC, age, and race/ethnicity to calculate BRI. This calculator is available at https://www.pbrc.edu/research-and-faculty/calculators/brc.aspx. When comparing various BRI values, researchers should check for these adjustments from the original equations and models by Thomas et al. (30). Whether BRI means for a mixed group or for men only and women only that are adjusted for these selection variables would be "different" after BWLPs may be explored in the future.

CONCLUSIONS

The Body Roundness Index is an anthropometric adiposity index that can be used to monitor individuals after weight loss. Because there are no standardized obesity cut-offs for BRI, further large scale populations should be studied to determine these cut-off scores. Practitioners may choose to continue to use traditional measures (e.g., SAD, WC, HC, %BF) as well as BRI to examine body shape changes in overweight and obese individuals before and after weight loss in order to monitor progress towards reaching goals.

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Validation of an 8-Minute Self-Paced Graded Exercise Testing Protocol to Elicit $\dot{V}O_2$ Max

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ABSTRACT

Graded exercise test (GXT) recommendations for measuring maximal oxygen consumption ($\dot{V}O_2$ max) allow for a duration of 10 ± 2 minutes. Previous literature has determined that self-paced 10-minute self-paced protocols (10SPV) can accurately measure $\dot{V}O_2$ max when performed correctly. The purpose of this study was to determine if an 8-minute self-paced protocol (8SPV) elicits a maximal exercise response comparable to the standardized GXT protocol and the 10SPV. Twenty-seven recreationally active college adults (age = 20.7 ± 1.3 years) completed 3 protocols in a randomized order: (a) 8SPV consisting of eight 1-minute stages clamped at an RPE_{6-20} of 11, 13, 14, 15, 16, 17, 18, and 20; (b) 10SPV consisting of five 2-minute stages clamped at an RPE_{6-20} of 11, 13, 15, 17, and 20; (c) Bruce protocol was used as the GXT, starting at a speed of 2.71 km/hr with a 10% grade and increasing speed and grade every 3 minutes until volitional exhaustion. 8SPV and 10SPV maintained a constant 3% grade. A one-way ANOVA with repeated measures was employed to examine differences in maximal responses between protocols (SPSS). Maximal values for 8SPV, 10SPV, and GXT showed no statistically significant difference ($P > 0.05$) for $\dot{V}O_2$ max (GXT = 51.6 ± 7.6, 8SPV = 50.3 ± 7.4, 10SPV = 52.2 ± 8.8 $ml \cdot kg^{-1} \cdot min^{-1}$), ventilation (GXT = 118.1 ± 31.5, 8SPV = 118.3 ± 34.7, 10SPV = 123.3 ± 36.2 $L \cdot min^{-1}$), respiratory exchange ratio (GXT = 1.13 ± 0.06, 8SPV = 1.12 ± 0.07, 10SPV = 1.12 ± .05), and maximal heart rate (GXT = 194.8 ± 11, 8SPV = 193.8 ± 10.4, 10SPV = 197.2 ± 8.3 $b \cdot min^{-1}$). Given no differences between protocols, 8SPV may serve as a valid and time efficient option to elicit maximal responses during exercise in recreationally trained college-aged individuals.

Key Words: Bruce Protocol, PRET, RPE-Clamped

INTRODUCTION

Graded exercise testing (GXT) and the measurement of maximal oxygen consumption ($\dot{V}O_2$ max) is one of the most widely examined variables in exercise science. The information gathered from GXT highlights the interaction between multiple physiological systems and allows practitioners and researchers to prescribe individual exercise, evaluate exercise tolerance, and determine the efficacy of intervention. Among the many factors that influence selection of the optimal GXT, recent examinations have turned to the total duration component of a test and the impact of duration on $\dot{V}O_2$ max. Current recommendations regarding total test duration stem from the American College of Sports Medicine (1), stating that tests lasting 10 + 2 minutes will elicit the highest $\dot{V}O_2$ max values. Since then, further examinations suggest that an optimal duration may depend on age, sex, modality, and training status (2,11). It has been postulated that the variability in maximal responses during traditional GXT is due to a failure to overcome 2 major limitations: (a) exercise intensity is determined by the tester as a part of the protocol; and (b) exerciser tests in an 'open-loop' environment in which the duration of the test is ultimately unknown. In effort to mitigate these issues, recent investigations have turned to the development and validation of perceptually regulated self-paced graded exercise testing protocols (SPV) because of their potential to elicit higher maximal physiological responses (2,7). Currently, the standard SPV is a 10-minute protocol consisting of $RPE_{6\text{-}20}$ (3) stages clamped at values of 11, 13, 15, 17, and 20 and has been shown to produce higher, similar, or lower $\dot{V}O_2$ max values (6).

A greater performance during SPV has been attributed to the 'competitive environment' element; wherein the exerciser is aware of the endpoint and exhibits a pacing strategy. Investigations highlighting similar $\dot{V}O_2$ max responses between SPV and traditional GXT comment on the overall utility of SPV as a valid testing alternative; however, manipulation of the SPV protocol has been limited. The original establishment of a 10-min duration in SPV is warranted, but there is reason to suggest that a shorter test duration could produce higher $\dot{V}O_2$ max values. Yoon et al. (11) compared maximal responses across GXT protocols of four different durations in moderate to highly trained males and females and found that shorter protocol durations (6 to 10 minutes) produce higher $\dot{V}O_2$ max values and that 88% of the men attained the highest $\dot{V}O_2$ max during the 8-minute protocol.

To our knowledge, no literature has manipulated total test duration in a self-paced velocity (SPV) design. The purpose of this study is to compare maximal responses during a traditional GXT, standard 10-minute SPV (10SPV), and an 8-minute SPV (8SPV) protocol on a treadmill. Furthermore, the 8SPV will consist of a different incremental workload design, using eight 1-minute RPE-clamped stages rather than the five 2-minute clamped stages. Results showing greater or similar maximal responses during the 8SPV would impact future utilization of perceptually-regulated GXT. In accordance with Yoon et al. (11), we hypothesize that a test duration of 8 minutes will elicit higher $\dot{V}O_2$ max, but similar maximal heart rate (HR_{max}), ventilation (VE_{max}), and respiratory exchange ratio (RER_{max}) values compared to a traditional GXT and 10SPV in recreationally active young men and women.

METHODS

Subjects

Twenty-seven college-aged males (n = 15) and females (n = 12) participated in the study. Their characteristics are provided in Table 1. The participants were considered recreationally active (no less than 30 minutes/day, 3 days/week for at least 3 months), between the ages of 18 and 25 years old, and were absent of known musculoskeletal, cardiovascular, metabolic, renal, or respiratory disease. The participants were recruited by means of informational posters at the University's educational and fitness facilities, word-of-mouth, and presenting to multiple University classes. The study protocol was reviewed and approved by the Institutional Review Board. All the participants provided written informed consent. As per the Helsinki Declaration, institutional ethical approval was obtained before the commencement of this study.

Table 1. Descriptive Data of the Subjects.

	Males (n = 15)	Females (n = 15)	Total (N = 27)
Age (years)	20.9 ± 1.4	20.4 ± 1.2	20.7 ± 1.3
Height (cm)	182.5 ± 5.6	162.0 ± 4.7	173.4 ± 11.6
Weight (kg)	82.9 ± 9.1	62.3 ± 6.2	73.7 ± 13.0
Body Mass Index ($kg{\cdot}m^{-2}$)	25.1 ± 2.3	23.3 ± 1.9	24.3 ± 2.3

Abbreviations: cm = centimeters, **kg** = kilograms; M = meters

Procedures

The current study required the participants to meet for 4 separate sessions over a 5-week period. The participants arrived at each session at the same time of day (± 2 hours) adhering to the pre-test guidelines: (a) consumption of a small meal 2 to 3 hours prior; (b) adequately hydrated; (c) refraining from vigorous exercise for 24 hours, and (d) avoiding caffeine and alcohol for 8 hours. Participants were also encouraged to maintain their current exercise regimen. Exercise sessions were completed over a 2-week period with individual trials separated by at least 48 hours but no more than 7 days. Temperature during all testing sessions was controlled between 20-22° C. The first session consisted of a familiarization session with an explanation of the RPE_{6-20}, overview of $\dot{V}O_2$ max testing, and a submaximal treadmill test. The submaximal familiarization test began with a 5-minute warm up at a self-selected speed equal to an RPE_{6-20} value of 11. This speed was used as the warm-up speed in all subsequent testing sessions. Following the warm-up, each participant completed three 2-minute stages at RPE_{6-20} values of 11, 13, and 15 to ensure conceptualization of ‘pacing strategy’.

The participants returned for 3 separate exercise testing sessions to perform a traditional GXT, 10SPV, and 8SPV in a randomized order. Each exercise session began with the barefoot measurement of height (HR-200; Tanita Corp. of America Inc., Arlington Heights, IL, USA) and body weight (Model 884, Seca, Hamburg Germany). The subjects were then refamiliarized with the RPE_{6-20} scale and were able to ask questions regarding the session. The Bruce protocol (4) was used as the traditional GXT. The 10SPV design has been described in previous literature. Briefly, it is comprised of five 2-minute stages corresponding to RPE_{6-20} value of 11 (light), 13 (somewhat hard), 15 (hard), 17 (very hard), and 20 (maximal). The 8SPV consisted of eight 1-minute RPE-clamped stages with targets of 11, 13, 14, 15, 16, 17, 18, and 20. The subjects were allowed to manipulate speed at any point during the SPV exercise tests via manual treadmill control. All SPV sessions were performed at 3% incline and the subjects were blinded from receiving speed and heart rate display feedback.

Metabolic data were collected and measured using an open-circuit indirect calorimetry (Medics TrueOne 2400, Parvo Medics, Salt Lake City, UT, USA), shown to have a validity of ± 3 to 4% (American Thoracic Society, 2003). The metabolic cart was calibrated before each exercise trial in accordance with manufacturer guidelines. Heart rate was collected continuously using a dual electrode chest strap heart rate monitor (H10, Polar Electro, Bethpage, NY, USA). All sessions were conducted on the same treadmill (Desmo S, Woodway, Waukesha, WI, USA). The mean of the highest 15 seconds and closest neighboring $\dot{V}O_2$ values during any 30-second period of the test were used as the $\dot{V}O_2$ max. Maximal oxygen consumption was verified by the presence of a $\dot{V}O_2$ plateau $\leq$ 150 ml/min and RER $\geq$ 1.1. Failure to obtain both criteria resulted in the subject repeating the trial on a separate day.

Statistical Analyses

All the data are presented as means ± SD. The data were initially evaluated at the univariate level for conformance with the assumptions for the ANOVA and *t*-test analyses. Sample size estimation was conducted using a priori power analysis (G*Power software, version 3.1.9.7), with the effect size set at 0.75 (5) and statistical power set at 0.80. The analysis indicated that a minimum of 6 total participants was required. A one-way ANOVA was used to examine any physiological differences in maximal exercise values between protocols. Upon establishing significance in the ANOVA model, a Bonferroni adjustment was performed and pairwise comparisons were examined. Bland-Altman 95% limits-of-agreement (LoA) were used to quantify the agreement (bias ± random error (1.96 x SD) between the GXT-8SPV and the 10SPV-8SPV $\dot{V}O_2$ max values. Significance was set a priori at $P < 0.05$. Statistical analyses were performed using IBM SPSS Statistics Software (Version 24, IBM Corp., Armonk, NY, USA).

RESULTS

There were no statistically significant interactions between protocols for $\dot{V}O_2$ max ($F(2, 27) = 3.004$, $P = 0.058$), HR_{max} ($F(2, 27) = 2.048$, $P = 0.164$), RER_{max} ($F(2, 27) = 0.975$, $P = 0.384$), and VE_{max} ($F(2, 27) = 1.634$, $P = 0.210$). Values for $\dot{V}O_2$ max are included in Table 2. While there was a trend towards significance, there was no difference for $\dot{V}O_2$ max attainment between GXT (51.9 ± 7.6 $ml \cdot kg^{-1} \cdot min^{-1}$), 8SPV (50.3 ± 7.4 $ml \cdot kg^{-1} \cdot min^{-1}$) and 10SPV (52.2 ± 8.8 $ml \cdot kg^{-1} \cdot min^{-1}$); P = .058, $\eta_p^2 = 0.104$.

Table 2. Maximal Responses during Three Graded Exercise Testing Protocols.

	GXT	8SPV	10SPV
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.5 ± 7.6	50.5 ± 7.0	53.2 ± 9.3
HR_{max} (bpm)	194.8 ± 10.9	193.7 ± 10.2	197.1 ± 8.3
RER_{max}	1.13 ± 0.06	1.12 ± 0.07	1.12 ± 0.05
VE_{max} ($L \cdot min^{-1}$)	121.6 ± 34.6	119.0 ± 33.8	125.5 ± 36.0

Abbreviations: GXT; graded exercise test, **8SPV**; 8-minute self-paced protocol, **10SPV**; 10-minute self-paced protocol, **VO_2 max**; maximal oxygen uptake, **HR_{max}**; maximal heart rate, **RER_{max}**; maximal respiratory exchange ratio, **VE_{max}**; maximal ventilatory equivalents.

Figure 1 shows comparisons of each $\dot{V}O_2$ max score to peak mean values across the 3 protocols. Bland-Altman plots for mean differences (95% limits of agreement) in $\dot{V}O_2$ max between the test protocols are shown in Figure 2. Only one participant is outside the bounds of the plot indicated as "a" establishing the relationship between GXT and 8SPV. Two participants were outside the bounds of the plot indicated as "b" establishing the relationship between 10SPV and 8SPV. The mean difference ± SD for all other dependent variables during 8SPV, 10SPV, and GXT is shown in Table 2. There was no difference in HR_{max} between GXT (194.8 ±11.0 $b \cdot min^{-1}$), 8SPV (193.8 ± 10.4 $b \cdot min^{-1}$), and 10SPV (197 ± 8.3 $b \cdot min^{-1}$); P = .190, $\eta_p^2 = 0.062$. There was no difference in RER_{max} between GXT (1.13 ± .06), 8SPV (1.12 ± .07), and 10SPV (1.12 ± .05); P = 0.384, $\eta_p^2 = .036$. Finally, there was no difference in VE_{max} between GXT (118.1 ± 31.5 $L \cdot min^{-1}$), 8SPV (118.3 ± 34.7 $L \cdot min^{-1}$), and 10SPV (123.3 ± 36.2 $L \cdot min^{-1}$); P = 0.210, $\eta_p^2 = .059$.

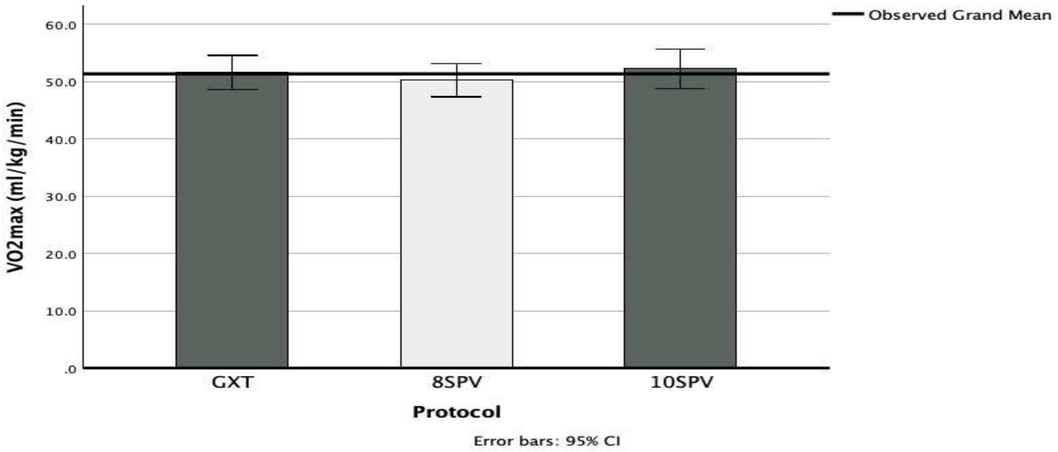

Figure 1. Group Maximal Oxygen Uptake: Responses during Standardized (GXT), 8-Minute Self-Paced (8SPV), and 10-Minute Self-Paced (10SPV) Protocols.

(A and B)

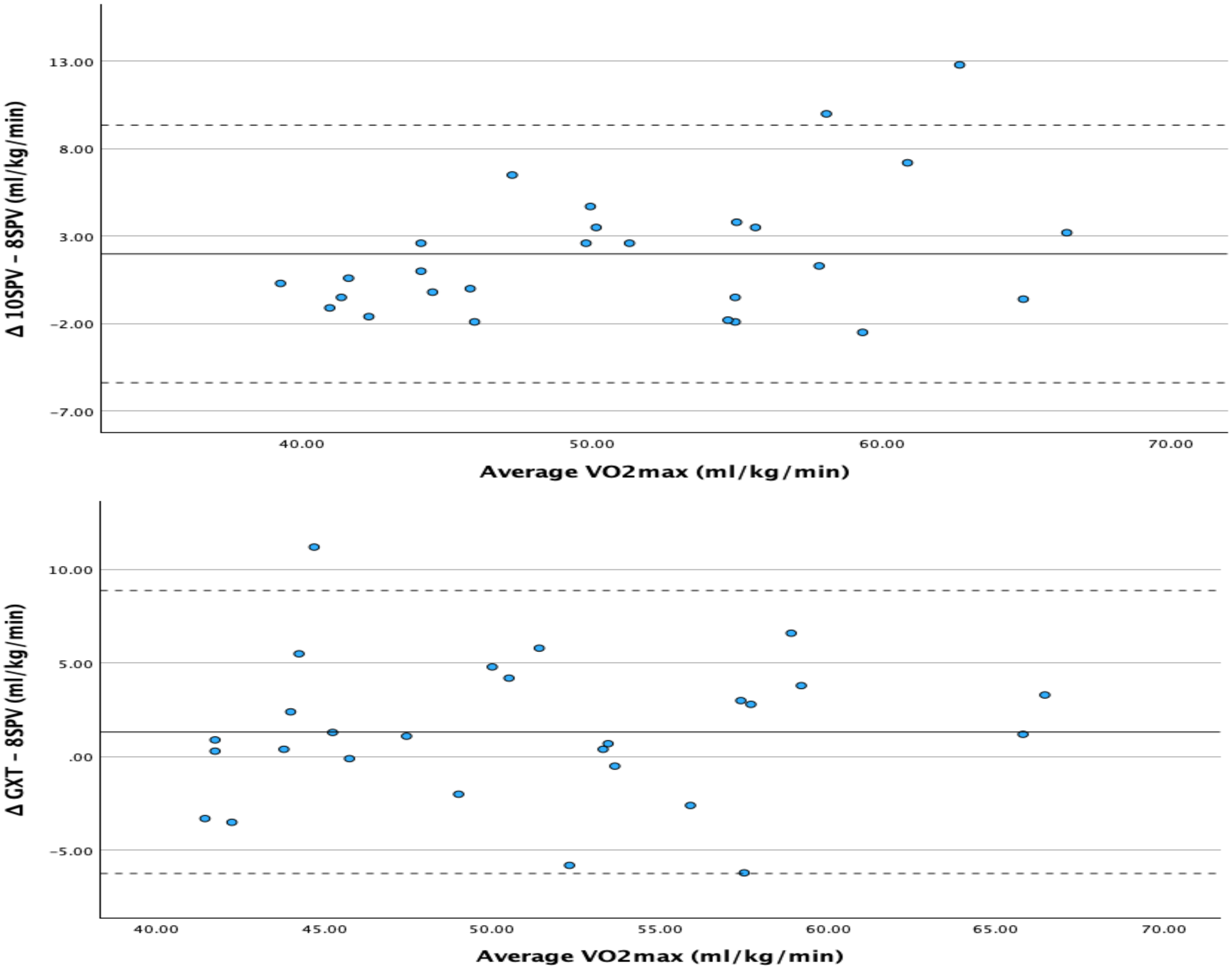

Figure 2. Bland-Altman Plots of (a) Bruce (GXT) vs. 8 Minute Self-Paced (8SPV) Protocol and (b) 10-Minute Self-Paced Protocol (10SPV) vs. 8-Minute Self-Paced (8SPV) Protocol for Comparison of Maximal Oxygen Consumption (VO_2 max).

DISCUSSION

The main findings of the current study indicated no difference in $\dot{V}O_2$ max values for group means as well as an individual basis between 8SPV, 10SPV, and GXT. However, a trend toward significance ($P = 0.058$) is likely due to lower $\dot{V}O_2$ max attainment during 8SPV compared to 10SPV and GXT. Further, there was no difference in HR_{max} or maximal RER between all protocols. To our knowledge, this is the first study to examine 2 SPV protocols of differing total time limits (e.g., 8 minutes and 10 minutes) compared to a standardized GXT (e.g., Bruce protocol) on a motorized treadmill.

Our findings agree with previous studies (5,6) that demonstrated no difference in $\dot{V}O_2$ max values between SPV and GXT. However, it should be noted when examining individual responses between the 3 protocols (e.g., 8SPV, 10SPV, and GXT), only 1 participant had the highest $\dot{V}O_2$ max value during the 8SPV protocol. Additionally, 8 of the 16 participants attained the lowest $\dot{V}O_2$ max value during the 8SPV compared to 10SPV and GXT. While 8SPV is within the recommended GXT duration of 8 to 12 minutes, it would appear a self-paced protocol completed in 8 minutes may be detrimental to attaining the highest $\dot{V}O_2$ max value in a population with 'Good' to 'Excellent' cardiorespiratory fitness as defined by the American College of Sports Medicine (1). Yoon and colleagues (11) examined $\dot{V}O_2$ max protocol duration using a cycle ergometer in men and women of relatively similar cardiorespiratory fitness to the participants in the current study. These researchers found that $\dot{V}O_2$ max values for women did not differ between 5-, 8-, 12-, and 16-minute protocols. However, men attained a significantly higher $\dot{V}O_2$ max value during the 8-minute protocol compared to all other durations. This is in direct opposition to the findings of the current study with two caveats: (a) the use of a cycle ergometer rather than treadmill; and (b) administering GXTs as opposed to self-paced protocols.

Other studies examining protocol duration (5,8,11) increased exercise intensity in a manner that might lead to volitional fatigue at an expected duration but was not well controlled. This elicited average protocol durations adjacent to the expected time to completion with ranges of ± 1- to 2-minute for shorter durations (i.e., 6-minute protocol) and ± 2- to 3-minute for longer durations (i.e., 12-minute protocol). This is the case in a study by McCole and colleagues (8), which utilized a motorized treadmill, recruited men and women subjects in excellent fitness as determined by $\dot{V}O_2$ max, and indicated no difference in $\dot{V}O_2$ max attainment between 3 different protocol durations. However, McCole and colleagues (8) found that maximal cardiac output was greatest in the short protocol duration (i.e., 6-minute test) compared to the traditional GXT and the long protocol duration (10-minute and 12-minute protocols, respectively). This finding potentially eliminates the possibility that our subjects were unable to reach a maximal cardiac output during the 8SPV compared to the 10SPV and the GXT.

Important to this discussion is the determination of *practical* vs. *statistical* significance in the case of $\dot{V}O_2$ max attainment between the protocols. While we did not calculate day-to-day variability in this study, previous research has suggested there is approximately a 2.6% physiological variability between the SPV trials (9,10) and the measurement error via metabolic system is typically 3 to 4%. The determination of total testing error would suggest that any tests within 5.6% can be considered practically similar, while tests outside of this range are practically different. In the current study, 12 of the 27 subjects were practically different when comparing 8SPV and GXT, with 8 of the 12 subjects from the 8SPV attaining a lower $\dot{V}O_2$ max. Further, 9 of 27 subjects were practically different when comparing 8SPV and 10SPV, with all 9 subjects from 8SPV attaining a lower $\dot{V}O_2$ max. Although the purpose of the current study was not to reassess suitability of 10SPV, 14 of the 27 subjects were practically different compared to GXT with 8 of the 14 subjects attaining higher $\dot{V}O_2$ max values in the 10SPV protocol.

We are prepared to assume that self-pacing mechanisms in the current 8SPV protocol may be negatively altered compared to the 10SPV protocol. Unique is the requirement to complete the test in the 8-minute and/or 10-minute duration and the use of RPE_{6-20} to determine treadmill speed (blinded to participant) during both protocols. When comparing both self-paced protocols, the 10SPV used five 2-minute stages at RPE_{6-20} values of 11 (light), 13 (somewhat hard), 15 (hard), 17 (very hard), and 20 (maximal), while the 8SPV used eight 1-minute stages at RPE_{6-20} values of 11, 13, 14, 15, 16, 17, 18, and 20. Upon further examination, a limitation of 8SPV may have been the shorter stages compared to the other 2 protocols. Shorter stages combined with specified RPE_{6-20} values with no corresponding perceived exertion language (like that of 10SPV) may have led to poor pacing strategies, despite the pre-testing familiarization. Future research may seek to examine a self-paced protocol that uses of four 2-minute stages at clamped RPE_{6-20} values (or ranges) for an exercise duration of 8 minutes. Furthermore, matching perception and pace could be achieved more successfully in an endurance-trained population with competitive racing experience.

CONCLUSIONS

The results of the present study demonstrate that $\dot{V}O_2$ max attainment was not statistically different between self-paced protocols at 8 minutes, 10 minutes, and the traditional GXT. However, practical significance would suggest that the 8-minute self-paced protocols using RPE-clamped stages 1-minute in duration may lead to reductions in $\dot{V}O_2$ max attainment when compared to the 10-minute self-paced protocol and the Bruce protocol. There was no difference in the other physiological variables (i.e., HR_{max}, RER, and VE_{max}) between the protocols.

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Validity and Reliability of Real-Time Skin Surface Thermometer and Infrared Thermometer

Juntip Namsawang[1], Phurichaya Werasirirat[1], Nutsupa Singhasoot[1], Oranat Sukkho[1], Pimonpan Taweekarn[1], Nongnuch Luangpon[1], Pornpimol Muanjai[1], Saw Wah Wah[2]

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ABSTRACT

Juntip Namsawang, Phurichaya Werasirirat, Nutsupa Singhasoot, Oranat Sukkho, Pimonpan Taweekarn, Nongnuch Luangpon,Pornpimol Muanjai, Saw Wah Wah. Thermotherapy is commonly used to manage pathological conditions. Also, it is used by healthy individuals, making reliable skin temperature monitoring clinically important. Skin temperature measurement is commonly performed to ensure safety and optimize therapeutic efficacy. The purpose of this study was to compare the validity and reliability of a real-time skin surface thermometer and an infrared thermometer in measuring skin temperature. Skin temperature was measured at the left arm and thigh in 100 healthy participants aged 18 to 25 years using both devices. Validity was assessed using Pearson correlation coefficients, and reliability was evaluated using intraclass correlation coefficients (ICC) based on a two-way mixed-effects model. Strong correlations were found between the two devices at both sites (upper arm: $r = 0.996$; thigh: $r = 0.967$; both $P < 0.001$). The real-time skin surface thermometer demonstrated excellent reliability (ICC = 0.998 and 0.983, respectively). These findings indicate that the real-time skin surface thermometer provides valid and reliable skin temperature measurements in healthy young adults and may be useful for monitoring skin temperature during thermotherapy in physical therapy settings.

Key Words: Reliability, Skin, Infrared, Thermometer, Validity

INTRODUCTION

The measurement of skin temperature has been employed in the diagnosis and monitoring of various pathological conditions, such as complex regional pain syndrome (CRPS), diabetic neuropathy, vascular insufficiency, vasospastic disorders, pressure ulcers (3), and burns (9). It is also clinically relevant in physical therapy, particularly in the application and monitoring of heat therapy. Thermotherapy is commonly used to relieve pain, improve circulation, support tissue healing, and reduce muscle stiffness, and it is applied in both hospital settings and home environments (10). However, excessive heat exposure during treatment increases the risk of thermal burns, particularly in older adults or individuals with impaired sensory perception, such as those with diabetes mellitus or peripheral vascular disease (8).

In clinical practice, the ability to measure skin surface temperature quickly and conveniently is beneficial. Various devices are available for this purpose. In particular, infrared thermometers are commonly used to measure skin surface temperature before or during heat therapy because they are safe, comfortable, portable, convenient, quick, and painless (4,11). However, these devices have certain limitations, including the lack of continuous monitoring, the need for manual operation, and the inability to provide automatic real-time alerts when skin temperature exceeds safe thresholds.

Thus, safety concerns associated with thermal interventions have led to a growing need for the development of innovative real-time skin surface thermometer systems capable of continuously monitoring skin temperature and providing immediate alerts when critical thresholds are reached. Such systems may improve the safety and clinical effectiveness of heat-based modalities by supporting timely decision-making and preventing heat-related adverse events. This is especially beneficial in rehabilitation settings with limited personnel or where simultaneous monitoring of multiple patients is required. Therefore, the purpose of this study was to compare the validity and reliability of a real-time skin surface thermometer and an infrared thermometer in measuring skin temperature.

METHODS

Subjects

A total of 100 healthy young adults participated in the study (22 men, 78 women; mean age 21.01 ± 1.38 years). Participants were recruited from Chonburi Province, Thailand, using convenience sampling. Inclusion criteria were: (a) age 18 years or older; (b) normal body mass index (BMI) between 18.5 and 22.9 kg/m² (7); and (c) ability to speak and communicate effectively to understand the study procedures. Exclusion criteria included: (a) scars, open wounds, or skin inflammation at the test site; (b) above-knee amputation on the tested side; (c) fever or body temperature exceeding 37.5°C (2); (d) impaired sensation in the tested limb; (e) neurological disorders (e.g., peripheral neuropathy); and (f) use of antipyretic medication within 8 hours prior to the study (6). The study was approved by the Research and Innovation Administration Division, Burapha University Ethics Committee (approval No. HS057/2566(C1)), and written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Procedures

Participants were instructed to wear a short-sleeved T-shirt and shorts and were seated in a room maintained at 25°C for 10 minutes to minimize external factors that could influence skin temperature measurements. During this time, the investigator cleaned the skin surfaces and marked two anatomical reference sites for temperature measurement: (a) 10 cm inferior to the anterior aspect of the acromion process and (b) 15 cm superior to the midpoint of the patella (Figure 1) (3).

A 0.6-cm-diameter circle was marked on the skin at two standardized anatomical sites on the left side of the body: the arm (over the common flexor muscle belly) and the thigh (over the rectus femoris). Skin temperature was measured within the marked areas using both a real-time skin surface thermometer and a non-contact infrared thermometer (Microlife NC200; Microlife AG, Widnau, Switzerland), which has a manufacturer-reported accuracy of ±0.2°C over a measurement range of 35.0-100.0°C. Measurements were performed following a standardized testing protocol that began at the arm and continued to the thigh.

A hot pack was applied to each of the two previously marked anatomical sites on the left upper arm and left thigh for a total duration of 30 minutes. The hot packs were prepared by heating them in a water bath maintained at 75°C and were wrapped in 10 layers of towels before being placed on the participant's skin (10). Skin temperature was recorded every 5 minutes during the intervention, with three repeated measurements obtained at each time point. All measurements were performed at the same anatomical locations.

To assess test–retest reliability, three consecutive measurements were taken at each time point for both devices, with approximately 5 seconds between measurements. All repeated measurements were performed within the same session to minimize natural variations in skin temperature. All assessments were conducted by a single examiner to ensure consistency in the measurement procedure.

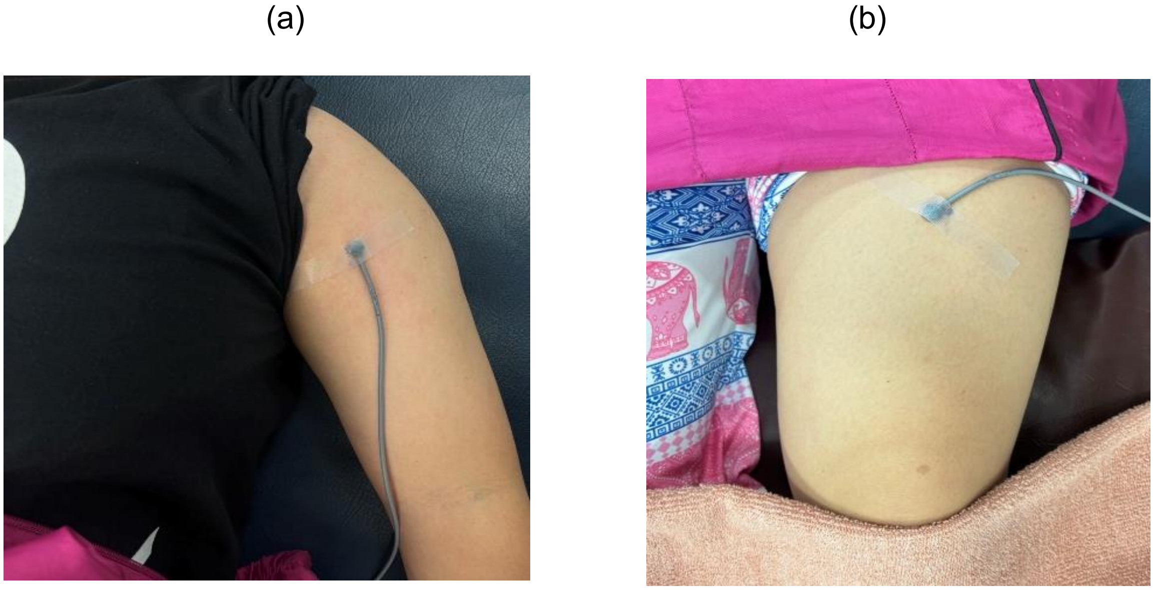

Figure 1. Measurement sites of skin temperature. The arm (a) and thigh (b). Skin temperature at each site was measured using a real-time skin surface thermometer and an infrared thermometer.

Statistical Analysis

The sample size was determined using G*Power software (version 3.1.9.2). The analysis was based on a significance level (α) of 0.05, a statistical power of 0.90, and an effect size of 0.367. The effect size was calculated using the mean and standard deviation of thigh skin temperature measured by thermistor (31.4 ± 1.2°C) and tympanic thermometer (30.9 ± 1.1°C), as reported by Burnham et al. (1). The required minimum sample size was estimated to be 81 participants. To account for a potential dropout rate of 20%, the target sample size was increased, and a total of 100 participants were recruited for the study.

All statistical analyses were performed using SPSS, version 30. Descriptive statistics were presented as mean (SD). Data normality was assessed using the Shapiro–Wilk test. Paired t tests were used to compare temperature measurements between the two devices at each site. Test-retest reliability was evaluated using the intraclass correlation coefficient (ICC[3,k]), based on a two-way mixed-effects model of absolute agreement, and 95% confidence intervals (CI) were reported. Concurrent validity was assessed using Pearson correlation coefficients. The significance level was $P < .05$.

RESULTS

A total of 100 participants were enrolled in this study, including 22 males and 78 females. The mean (SD) age of participants was 21.01 (1.38) years. The mean (SD) body weight was 60.14 (12.15) kg, mean (SD) height was 164.00 (7.41) cm, and the mean (SD) body mass index (BMI) was 22.25 (4.17) kg/m².

Skin temperature measurements obtained using the real-time skin surface thermometer at the left arm and left thigh were not significantly different from those recorded by the infrared thermometer (Table 1). Both devices demonstrated excellent test–retest reliability, with intraclass correlation coefficients of 0.99 for the real-time skin surface thermometer and 0.99 for the infrared thermometer at both measurement sites (Table 2-3).

Table 1. Skin Surface Temperature Measured by Two Different Devices (n = 100).

Time (min)	Real-Time Thermometer (°C)		Infrared Thermometer (°C)	
	Left arm	**Left thigh**	**Left arm**	**Left thigh**
0	31.04 (1.70)	29.86 (1.59)	31.05 (1.70)	29.87 (1.59)
5	37.69 (2.13)	36.94 (2.33)	37.70 (2.13)	36.97 (2.29)
10	39.11 (1.44)	38.80 (1.57)	39.11 (1.45)	38.86 (1.59)
15	39.09 (1.12)	38.96 (1.14)	39.10 (1.11)	38.97 (1.15)
20	38.66 (1.12)	38.52 (0.88)	38.68 (1.11)	38.56 (0.90)
25	38.20 (0.87)	37.98 (0.90)	38.23 (0.86)	38.03 (0.83)
30	37.74 (0.77)	37.49 (0.98)	37.76 (0.76)	37.58 (1.07)

The data are expressed as mean (SD). Abbreviations: °C = degrees Celsius. Temperature measurements from the two devices were compared within the same participants at each time point using paired *t*-tests ($P < 0.05$).

Table 2. Concurrent Association Between Temperature Measurements Obtained Using Two Devices (n = 100).

Area	Real-Time Thermometer	Infrared Thermometer	Pearson r	P-values
Left Arm	37.36 (0.89)	37.38 (0.89)	0.996	< 0.001
Left Thigh	36.94 (0.91)	36.98 (0.91)	0.967	< 0.001

The data represent Pearson correlation coefficients (r), indicating the strength of the association between the temperature values obtained from the real-time skin surface thermometer and the infrared thermometer.

Table 3. Reliability Between the Real-Time Skin Surface Thermometer and Infrared Thermometer (n = 100).

Area	ICC	95%CI
Left Arm	0.998	0.997 - 0.999
Left Thigh	0.983	0.975 – 0.989

The data represent intraclass correlation coefficients (ICC) with 95% confidence intervals, indicating test–retest reliability between devices. ICC was calculated using a two-way mixed-effects model with absolute agreement.

DISCUSSION

The present study evaluated the validity and reliability of a real-time skin surface thermometer in comparison with a commonly used infrared thermometer during thermotherapy. The results indicated that the temperature values obtained from both devices were highly comparable at the arm and thigh measurement sites. In addition, both instruments demonstrated excellent test–retest reliability, with ICC values greater than 0.98, indicating that the measurements were stable and consistent.

The strong correlations observed between the two devices support the concurrent validity of the real-time thermometer. These findings are consistent with those reported by Burnham et al. (3), who found that properly calibrated skin surface thermometers provide accurate and reliable measurements when standardized procedures are applied. Similar findings have been reported in studies evaluating infrared thermometry in the clinical settings (4,5,11).

Accurate monitoring of skin temperature is important during thermotherapy to minimize the risk of excessive heat exposure and thermal injury. This is important because previous studies have reported that inappropriate heat application may lead to skin damage, particularly in individuals with reduced sensation or impaired circulation (9,10). Accordingly, reliable temperature measurement remains an important component of safe clinical practice.

Although infrared thermometers are widely used due to their convenience and non-contact characteristics, they provide only intermittent measurements and require repeated manual operation (4). In contrast, the real-time thermometer evaluated in this study allows continuous, hands-free temperature monitoring and provides real-time alerts when temperature thresholds are exceeded. This feature may support earlier detection of abnormal temperature changes, facilitate timely clinical intervention, and help address important safety concerns, particularly in vulnerable populations.

Continuous monitoring may be particularly beneficial in clinical environments where therapists are responsible for multiple patients simultaneously. In addition, older adults and individuals with chronic conditions, such as diabetes mellitus may be more vulnerable to thermal injury (10). Therefore, the use of real-time monitoring devices may contribute to improved treatment safety in these populations.

Previous studies have demonstrated the limitations of infrared thermometry, particularly its inability to detect rapid temperature changes or provide automatic alerts (1). The real-time thermometer evaluated in this study contributes to addressing these limitations by offering continuous monitoring while maintaining measurement accuracy and clinical practicality. As technology-assisted rehabilitation continues to increase, real-time temperature monitoring may be considered a useful addition to existing safety protocols for thermotherapy. In clinical practice, the present findings also suggest that such systems could be incorporated into routine care as a supplementary safety measure. Furthermore, as sensor-based and digital monitoring technologies continue to expand in rehabilitation, these devices may provide additional support for clinical decision-making.

Limitations in this Study

This study was conducted in a controlled environment with healthy young adults that may limit the generalizability of the findings to older adults or patients with comorbid conditions, such as diabetes or peripheral vascular disease. Additionally, the intervention used a standardized hot pack protocol, which may not fully represent variations in thermotherapy techniques across clinical settings. Future studies should include other age groups, clinical populations, and additional heat-therapy modalities or devices to determine whether these findings apply beyond healthy young adults.

CONCLUSIONS

The real-time skin surface thermometer demonstrated high reliability and validity compared with a standard infrared thermometer. Its ability to provide continuous temperature monitoring and real-time alerts offers a valuable enhancement to current thermotherapy practices. If validated in clinical settings, real-time temperature monitoring could be a useful complement to existing practices for managing heat therapy.

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The Impact of Long-Distance Cycling Exercise on Balance Performance and Risk of Fall in Older Adults

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ABSTRACT

Tangchaisuriya P, Preedalikit K, Chuensiri N. The Impact of Long-Distance Cycling Exercise on Balance Performance and Risk of Fall in Older Adults. The purpose of this study was to determine the impact of long-distance cycling training on balance performance and fall risk in older adults. The participants included 18 older male cyclists in the Cycling Group and 17 older male adults in the Control Group who did not exercise (average ages 67.7 ± 4.75 years and 68.5 ± 5.36 years, respectively, with P = 0.617). The participants were matched for age, gender, and height. The participants in the Cycling Group engaged in high-intensity cycling sessions 4 to 6 times per week, maintaining speeds exceeding 25 km/h, which qualifies as vigorous exercise. In contrast, the Control Group comprised participants who engaged in minimal or no physical activity. The Mini-BEST Test was performed on all participants. The Cycling Group had significantly higher total balance scores (23.2 ± 2.44 versus 20.1 ± 2.45, P = 0.001). For anticipatory postural adjustments, the total score was higher in the Cycling Group (5.50 ± 0.51 versus 5.06 ± 0.55, P = 0.020). In reactive postural control, compensatory stepping backward was significantly better in the Cycling Group (1.28 ± 0.66 versus 0.71 ± 0.58, P = 0.011). For sensory orientation, the Cycling Group scored significantly higher (5.67 ± 0.59 versus 5.00 ± 0.79, P = 0.008). Specifically, performance on stance with feet together on foam with eyes closed (1.67 ± 0.59 versus 1.29 ± 0.47, P = 0.048) and stance on incline with eyes closed (2.00 ± 0.00 versus 1.65 ± 0.60, P = 0.029) was significantly better. Dynamic gait assessment showed a significantly higher total score in the Cycling Group (8.39 ± 1.09versus 6.88 ± 1.31, P = 0.001). Walk with pivot turns (1.72 ± 0.46 versus 1.29 ± 0.58, P = 0.022) and timed up and go with dual task (0.89 ± 0.58 versus 0.24 ± 0.43, P = 0.001) performed significantly better in the Cycling Group. Cycling serves as an effective intervention for enhancing balance and mitigating the risk of falls.

Key Words: Balance, Cycling, Fall Risk, Older Adult

INTRODUCTION

With the global population aging rapidly, the importance of maintaining postural stability and preventing falls has intensified, as these factors are crucial determinants of health and independence among older adults (9,15). Age-related declines in sensory, musculoskeletal, and neurological systems contribute to impaired balance, increasing the risk of falls that can lead to severe injuries, reduced mobility, and diminished quality of life (8,24,29). Preventing falls in the elderly improves individual well-being and alleviates the burden on caregivers and medical resources. Strategies include comprehensive assessments of balance and gait, tailored exercise programs that focus on strength and proprioception, and environmental modifications to minimize hazards (6,23). Integrating these approaches within geriatric care promotes safer aging, supports functional independence, and addresses the broader public health challenge posed by an aging demographic. Comprehensive assessments, such as the Mini-Balance Evaluation Systems Test (Mini-BESTest) are essential for identifying specific deficits across the 4 critical balance subsystems: anticipatory adjustments, reactive control, sensory orientation, and dynamic gait (19,27,30). These assessments enable clinicians to design personalized intervention plans that target the underlying impairments contributing to fall risk.

Age-related physiological decline adversely affects multiple systems critical for maintaining postural stability, including sensory integration, neuromuscular coordination, and musculoskeletal strength. This decline often results in impaired balance, which significantly increases the risk of falls and associated morbidity among older adults (3,8,31). While traditional interventions have predominantly focused on strength training, tai chi, and balance-specific exercises to mitigate these effects, emerging evidence suggests that endurance activities, such as long-distance cycling may offer complementary benefits (1,4,7,18,29). Cycling not only promotes cardiovascular health but also enhances lower limb muscle endurance and coordination, which are essential components for dynamic balance and fall prevention (3,10,22).

Interventions for older adults have been explored with various approaches to enhance balance, lower limb strength, and overall functional mobility. Structured cycling programs often involve moderate to vigorous intensity sessions, performed multiple times per week to improve cardiovascular endurance and muscular coordination. For example, stationary cycling protocols have been used to provide a controlled, low-impact environment that allows gradual progression tailored to individual capabilities and health status. These interventions typically last from 6 to 12 weeks, with session durations ranging from 20 to 45 minutes, emphasizing consistency and gradual overload to promote neuromuscular adaptations relevant to balance control (14,17). In addition to stationary cycling, outdoor or recumbent cycling programs have been implemented to engage dynamic postural adjustments and proprioceptive feedback, which are critical for real-world balance and fall prevention. Some interventions combine cycling with balance-specific exercises or resistance training to target multiple physiological systems simultaneously (28). Such multimodal programs have demonstrated improvements in gait stability, reaction time, and lower limb muscle endurance. Moreover, cycling interventions often incorporate monitoring tools, such as heart rate or perceived exertion scales to optimize intensity and ensure safety (1,5). These approaches underscore cycling's versatility as both a standalone and complementary exercise modality in comprehensive fall prevention strategies for the elderly.

However, evidence regarding the effects of long-distance cycling on dynamic balance remains limited. Understanding the impact of long-distance cycling on dynamic balance is crucial, especially for populations at risk of falls or balance impairments. Dynamic balance involves maintaining stability while in motion and is essential for functional mobility and injury prevention (12,20). Dynamic balance involves maintaining stability while in motion and is essential for functional mobility and injury prevention (12,20,26). Investigating this relationship could inform targeted exercise recommendations and rehabilitation strategies. The purpose of this study was to examine the impact of long-distance cycling training on balance performance and fall risk in older adults. We hypothesized that cyclists would demonstrate significantly superior balance measures and a corresponding reduction in fall risk.

METHODS

Subjects

The study's participants included 18 older male cyclists in the Cycling Group and 17 older male adults in the Control Group who did not exercise (average ages 67.7 ± 4.75 years and 68.5 ± 5.36 years, respectively, with P = 0.617). These individuals were chosen through purposive sampling from Phayao province. Those in the Cycling Group participated in regular high-intensity cycling sessions 4 to 6 times weekly, maintaining speeds exceeding 25 km/h, which is considered vigorous to high intensity according to Metabolic Equivalent (MET) standards. Conversely, the Control Group comprised individuals who were either sedentary or engaged in minimal physical activity. The Cycling Group demonstrated a significantly higher level of physical activity (4823 ± 2016 MET-min/week) compared to the Control Group (2742 ± 2067 MET-min/week; P = 0.005) (Table 1). All the participants gave informed consent to join the study. The University of Phayao's human research ethics review committee approved the study (HREC-UP-HSST 1.2/09268) on May 11, 2025. The participants were briefed on the procedures, benefits, and potential risks before signing the informed consent. The study received approval from the University of Phayao's human research ethics review committee.

Procedures

Measurements were conducted in the exercise and sport science laboratory at University of Phayao. 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. Then the participants completed a health history questionnaire.

The Mini-Balance Evaluation Systems Test (Mini-BESTest) is a validated clinical assessment tool used to evaluate dynamic balance by examining 4 key aspects of postural control. It consists of 14 tasks, each scored on a 0 to 2 scale, resulting in a maximum total score of 28 points; higher scores indicate better balance performance and postural control (9,25). This test is widely applicable, particularly for older adults and individuals with neurological conditions that affect balance. Administration is conducted by a trained evaluator who provides clear explanations and demonstrations of each task to ensure accurate participant performance. To control fatigue and maintain assessment accuracy, a standardized rest period of 1 minute was given between the tasks (19). This methodological approach ensures reliable measurement of balance capabilities, making the Mini-BESTest a practical and robust tool for identifying balance deficits and monitoring changes over time in clinical populations.

Table 1. Descriptive Data of Anthropometric and Physiological.

Characteristics	Cycling Group (N = 18)	Control Group (N = 17)	P value
Age (yrs)	67.7 ± 4.75	68.5 ± 5.36	0.617
Height (cm)	164 ± 5.95	161 ± 6.02	0.193
Weight (kg)	60.3 ± 10.40	50.5 ± 8.35	0.004*
Exercise Status	- Regular cycling exercise, predominantly continuous training, frequency 4 to 6 days/week - Average speed >25 km/hr that corresponds to vigorous to high intensity levels based on metabolic equivalent of task (MET) standards	- Non-cycling exercise and routine daily activities - Sedentary or light physical activity	N/A
Physical Activity (PA)			
Cycling Time	>450 min/week	N/A	
PA Volume (MET-min/week)	4823 ± 2016	2742 ± 2067	0.005*

*Indicates statistical significance (P < 0.05).

Statistical Analyses

Data analysis was conducted using SPSS (version 25; IBM Corp., Armonk, NY, USA). The Shapiro-Wilk Test was employed to check the normality of each variable, while the Levene's Test was used to evaluate the homogeneity of variance. Descriptive statistics, including means and standard deviations (mean ± SD), were computed for the participants. The differences between the 2 Groups were examined using independent samples *t*-tests. A P-value of less than 0.05 was considered statistically significant for all comparisons.

RESULT

The Groups were matched in age (67.7 ± 4.75 years versus 68.5 ± 5.36 years, P = 0.617) and height (164 ± 5.95 cm versus 161 ± 6.02 cm, P = 0.193) (Table1). The Cycling Group achieved significantly higher total balance scores (23.2 ± 2.44 versus 20.1 ± 2.45, P = 0.001). For anticipatory postural adjustments, the total score was higher in the Cycling Group (5.50 ± 0.51 versus 5.06 ± 0.55, P = 0.020). In reactive postural control, compensatory stepping backward was significantly better in the Cycling Group (1.28 ± 0.66 versus 0.71 ± 0.58, P = 0.011). For sensory orientation, the Cycling Group scored significantly higher (5.67 ± 0.59 versus 5.00 ±

0.79, P = 0.008). Specifically, performance on stance with feet together on foam with eyes closed (1.67 ± 0.59 versus 1.29 ± 0.47, P = 0.048) and stance on incline with eyes closed (2.00 ± 0.00 versus 1.65 ± 0.60, P = 0.029) was significantly better. Dynamic gait assessment showed a significantly higher total score in the Cycling Group (8.39 ± 1.09 versus 6.88 ± 1.31, P = 0.001). Walk with pivot turns (1.72 ± 0.46 versus 1.29 ± 0.58, P = 0.022) and timed up and go with dual task (0.89 ± 0.58 versus 0.24 ± 0.43, P = 0.001) was performed significantly better in the Cycling Group (Table 2).

Table 2. Mini-Balance Evaluation Systems Test Score.

Characteristics	Cycling Group (N = 18)	Control Group (N = 17)	P value
Total Score of Anticipatory Postural Adjustments	**5.50 ± 0.51**	**5.06 ± 0.55**	**0.020***
Sit to stand	2.00 ± 0.00	2.00 ± 0.00	1.000
Rise to toes	2.00 ± 0.00	1.82 ± 0.39	0.083
Stand on one leg	1.50 ± 0.51	1.18 ± 0.52	0.076
Total Score of Reactive Postural Control	**3.67 ± 1.32**	**3.06 ± 0.96**	**0.133**
Compensatory stepping forward	1.44 ± 0.51	1.41 ± 0.50	0.851
Compensatory stepping backward	1.28 ± 0.66	0.71 ± 0.58	0.011*
Compensatory stepping lateral	0.94 ± 0.72	0.82 ± 0.63	0.604
Total Score of Sensory Orientation	**5.67 ± 0.59**	**5.00 ± 0.79**	**0.008***
Stance (feet together) on firm surface	2.00 ± 0.00	2.00 ± 0.00	1.000
Stance (feet together) on foam, eyes closed	1.67 ± 0.59	1.29 ± 0.47	0.048*
Stance on incline, eyes closed	2.00 ± 0.00	1.65 ± 0.60	0.029*
Total Score of Dynamic Gait	**8.39 ± 1.09**	**6.88 ± 1.31**	**0.001***
Change in gait speed	2.00 ± 0.00	1.94 ± 0.24	0.332
Walk with head turns	1.78 ± 0.42	1.41 ± 0.71	0.079
Walk with pivot turns	1.72 ± 0.46	1.29 ± 0.58	0.022*
Step over obstacles	1.94 ± 0.23	1.76 ± 0.43	0.146

Characteristics	Cycling Group (N = 18)	Control Group (N = 17)	P value
Timed Up and Go with dual task	0.89 ± 0.58	0.24 ± 0.43	0.001*
Total Balance Score	**23.2 ± 2.44**	**20.1 ± 2.45**	**0.001***

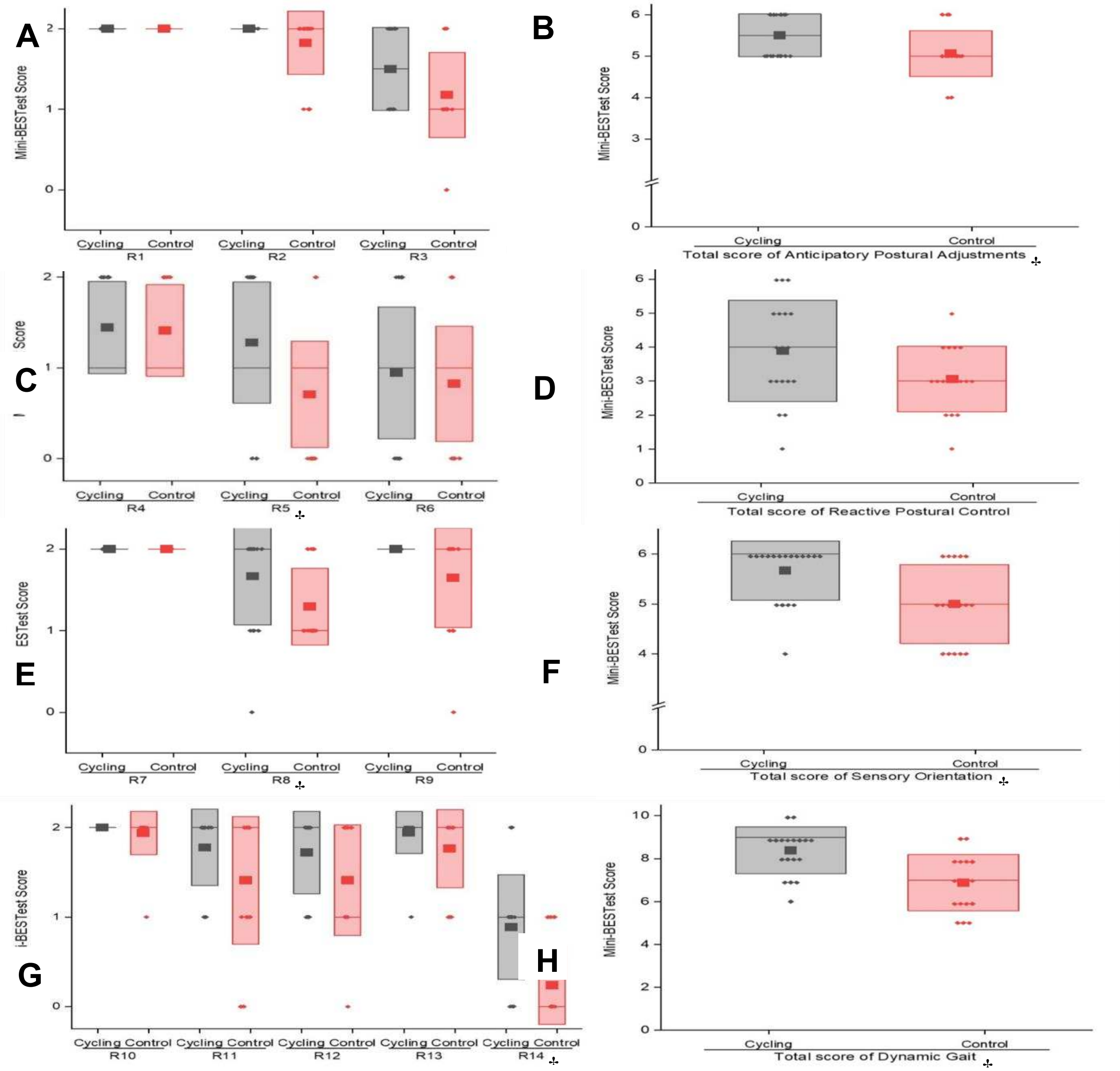
*Indicates statistical significance (P < 0.05).

DISCUSSION

The findings from the Mini-Balance Evaluation Systems Test (Mini-BESTest) provide compelling evidence that regular cycling uniquely preserves multidimensional balance and neuromuscular coordination in older adults. Notably, the Cycling Group demonstrated significantly superior anticipatory postural adjustments (APAs) and reactive postural control, especially during compensatory backward stepping. Age-related declines in APAs and delayed reactive stepping are primary mechanical contributors to an increased risk of falls (Figure 1). This is consistent with similar studies that have reported age-related increases in scaling exponents, suggesting that young adults use a more complex and more tightly regulated postural control strategy (12,16). Cycling inherently challenges these systems, as it demands continuous, rapid shifts of the center of mass over a narrow base of support to maintain equilibrium (21). Engaging in cycling involves the alternating movement of both legs with equal intensity, which can potentially improve muscle strength and balance. The disparity in balance between the Cycling Group and the Control Group might be partially attributed to the differences in their levels of physical activity. Cyclists engaged in significantly more physical activity than non-cyclists. Research indicates that physical activity can help reduce the risk of falls (24). Regular cycling acts as a dynamic "calibration tool" for the aging nervous system, specifically by enhancing the body’s proprioceptive feedback loops.

Unlike the repetitive and often automated nature of walking, cycling requires the brain to constantly integrate sensory input from the vestibular system, vision, and mechanoreceptors in the joints to maintain an upright position on a moving base (13,16). This constant "sensory re-weighting" compels the central nervous system to prioritize accurate balance signals over the "noisy" or degraded data often associated with aging. Consequently, older cyclists tend to maintain a more precise internal map of their body’s position in space, which is a fundamental requirement for the high scores observed in the sensory orientation and dynamic gait sections of the Mini-BESTest. Furthermore, the cycling cohort demonstrated superior sensory orientation, particularly when standing on foam or inclined with the eyes closed, underscoring their enhanced reliance on and efficiency of the somatosensory, proprioceptive, and vestibular systems. In conditions where their eyes are open, cyclists exhibited less sway velocity compared to non-cyclists. This indicates that cyclists employ a more precisely controlled postural strategy, which might be linked to enhanced stability (26). This is consistent with similar studies that have reported age-related increases in scaling exponents, suggesting that young adults use a more complex and more tightly regulated postural control strategy (12,13). This preservation enables individuals to maintain stability even when visual and somatosensory inputs are compromised or conflicting. By consistently challenging the body to respond to external perturbations and shifting centers of gravity, cycling aids in preserving the rapid neuromuscular timing necessary to execute a compensatory step and prevent falls (11).

Figure 1. The Box (Means ± SD) Plots and Scatterplots Demonstrating Paired Data of the Cycling Group (gray box) and the Control Group (red box) in Mini-BESTest Scores.

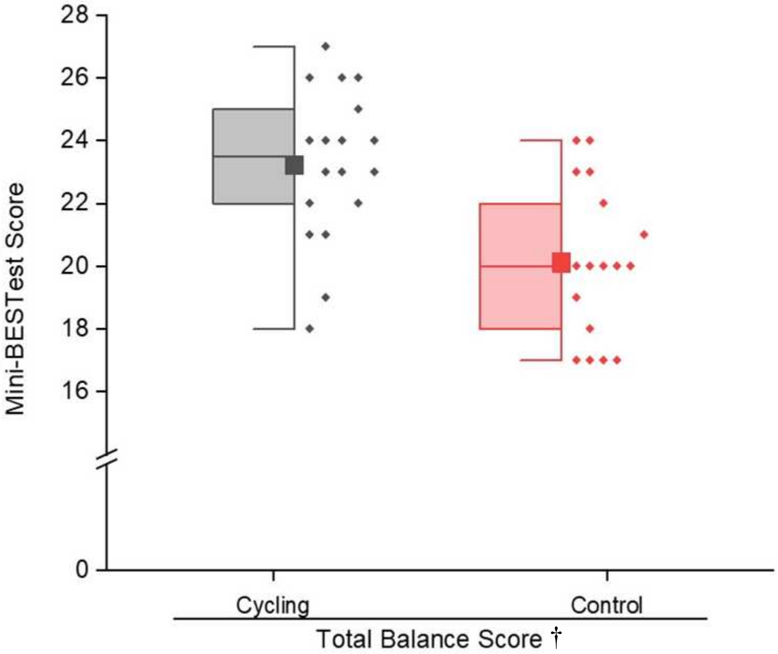


Total score of Anticipatory Postural Adjustments; R1-Sit to stand, R2-Rise to toes, R3-Stand on one leg (A, B). Total score of Reactive Postural Control; R4-Compensatory stepping forward**,** R5-Compensatory stepping backward, R6-Compensatory stepping lateral (C, D). Total score of Sensory Orientation; R7- Stance (feet together) on firm surface, R8- Stance (feet together) on foam, eyes closed, R9- Stance on incline, eyes closed (E, F). Total score of Dynamic Gait; R10-Change in gait speed**,** R11-Walk with head turns**,** R12-Walk with pivot turns**,** R13-Step over obstacles**,** R14-Timed Up and Go with dual task (G, H). †P < 0.05 versus between Group.

Beyond static and reactive balance, the Cycling Group demonstrated significantly superior dynamic gait and dual-task performance, as shown by their enhanced ability in walking with pivot turns and completing the timed up-and-go (TUG) test with a dual cognitive task. The Cyclist Group showed improvements in preferred- and fast-paced gait speeds (2). Effective cycling requires the ability to self-launch, pedal, turn, brake, and maintain the stability of both the body and the bicycle. Therefore, successful cycling demands the control and coordination of one's own degrees of freedom (i.e., motor units, muscles, and joints) while simultaneously managing external degrees of freedom (i.e., pedals, steering wheels, and brakes). This integration creates a unified, stable, and functional system with the bicycle in the environment.

Navigating a bicycle in a real-world setting is an inherently complex cognitive-motor task. It involves the simultaneous execution of repeated motor patterns (pedaling and steering) while continuously processing exteroceptive environmental stimuli (scanning for traffic and anticipating obstacles) and executing executive functions. This habitual "motor-cognitive" training likely induces neuroplasticity in the prefrontal cortex and basal ganglia, thereby reducing the cognitive-motor interference typically observed in older adults (33,34,35). Consequently, the significantly faster dual-task TUG completion time in the Cycling Group suggests that the automated locomotor control developed through cycling frees up cognitive resources, directly translating to improved functional ambulation and a dramatically lower fall risk during real-world distracting conditions. Table 1 indicates that the Cycling Group is significantly of greater weight than the Control Group. Because of the activity of the Cycling Group, it is possible their lean body mass is attributable to this difference in body weight. This could be a contributing factor in the greater balance in the Cycling Group (Figure 2).

Figure 2. Comparison of Mean Total Mini-BESTest Scores between the Cycling Group (gray box) and the Control Group (red box).



CONCLUSIONS

Regular cycling may serve as a low-impact exercise that effectively enhances dynamic balance and postural control. This suggests that the sensory-motor demands of cycling mitigate age-related degradation of the balance system, ultimately providing a protective effect against falls compared to a sedentary lifestyle

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Fat-Derived Energy Expenditure During Interval vs. Constant Speed Walking in Healthy Sedentary Adults

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ABSTRACT

Esho A, Choi MD. Fat-Derived Energy Expenditure During Interval vs. Constant Speed Walking in Healthy Sedentary Adults. Walking is a widely accessible, low-risk form of physical activity that is commonly used for weight management. This study compared the effects of interval walking (INT) and constant speed walking (CON) on fat-derived energy expenditure and plasma glycerol responses in healthy sedentary adults. Hence, this study determined whether INT walking produces greater fat-derived energy expenditure than constant speed walking in healthy sedentary adults. A randomized crossover design was employed with 14 healthy sedentary participants (BMI ≤25 kg/m²; age 18 to 50 years). The CON consisted of 60 min of treadmill walking at 45% of VO_2 peak while INT consisted of 60 min of alternating 3-min bouts at 30%, 45%, and 60% of VO_2 peak. Energy expenditure was assessed via indirect calorimetry. Plasma glycerol was measured at rest and every 10 min during exercise. The data were analyzed using appropriate repeated-measures and paired statistical tests with the significance set at $P < 0.05$. The findings indicated that the rate of fat-derived energy expenditure over time and mean net energy expenditure from fat did not differ significantly between INT and CON conditions during exercise. Plasma glycerol concentrations were not different between the conditions. However, within both conditions, glycerol was significantly elevated at 50 and 60 min compared to 10 min of exercise ($P < 0.05$). The findings indicated that Interval and constant speed walking produced similar fat-derived energy expenditure responses. Exercise duration, rather than speed variation, may be a more important stimulus for lipolysis during low-to-moderate intensity walking.

Keywords: Energy Expenditure, Indirect Calorimetry, Interval Walking, Sedentary Adults, Lipolysis

INTRODUCTION

Obesity has reached epidemic proportions globally with the World Health Organization (WHO) estimating that over one billion individuals are overweight, of whom approximately 650 million are clinically obese (24). Overweight and obesity are associated with increased risk of chronic disease, including type 2 diabetes, hypertension, stroke, and cardiovascular disease (24). The widely accepted etiology of obesity involves a chronic imbalance between energy intake and energy expenditure (11). Regular physical activity is one of the most effective strategies to increase daily energy expenditure and improve metabolic health. The American College of Sports Medicine recommends at least 150 min per week of moderate-intensity aerobic exercise or 75 min per week of vigorous-intensity exercise for health maintenance (9).

Walking is among the most practical, accessible, and low-risk forms of exercise with documented benefits for weight management and cardiovascular health (14,16,17). Although running expends more energy than walking at a given time point (10), walking remains a preferred mode of exercise given its low barrier to entry and injury risk. Fat oxidation during walking is comparable to that during running in both normal-weight and obese individuals (3), and prolonged low-intensity walking has been shown to elevate circulating free fatty acids (FFA) and glycerol (20). Furthermore, 30 min of walking 5 days per week has been associated with a 19% reduction in coronary heart disease risk (25).

Walking also shows promise in the management of type 2 diabetes, which is a condition strongly linked to abdominal adiposity and insulin resistance (22). Aerobic exercise reduces visceral fat, improves glucose homeostasis, and enhances insulin sensitivity (6,13). Interval walking training, which alternates between low- and high-intensity bouts, has been shown to produce greater improvements in physical fitness, body composition, glycemic control, and VO_2 max compared to continuous walking in type 2 diabetic populations (14).

However, existing research on interval vs. continuous walking has been primarily conducted in obese or diabetic populations, with fewer studies examining these modalities in healthy, sedentary adults. Campbell et al. reported no significant difference in VO_2 max or body composition between interval and continuous walking in an obese cohort with caloric restriction, though VLDL levels improved with interval walking (5). Murphy et al. reported, based on a review of empirical studies, that intermittent brisk walking was associated with greater improvements in VO_2 max than continuous walking, along with favorable changes in cholesterol profiles in both conditions (15). Despite these findings, the acute effects of interval vs. constant speed walking on total-body energy expenditure and fat-derived energy expenditure in healthy, sedentary individuals with low metabolic risk remain understudied.

Therefore, the purpose of this study was to compare the acute effects of a single session of interval walking (INT) versus constant speed walking (CON) on fat-derived energy expenditure and plasma glycerol responses in healthy, sedentary adults. We hypothesized that INT would elicit greater fat-derived energy expenditure than CON due to its inclusion of higher-intensity exercise intervals.

METHODS

Participants

Fourteen healthy sedentary adults (N = 14) were recruited via flyer distribution on the Oakland University campus, Rochester, MI. Inclusion criteria included: age 18 to 50 years, BMI ≤25 kg/m², and self-reported physical inactivity (no regular structured exercise routine). This study was approved by the Oakland University Institutional Review Board (IRBNet #1214642-2), and all the participants provided written informed consent prior to enrollment.

Study Design

A randomized crossover design was employed. Each participant completed both the CON and INT conditions in a counterbalanced random order, with a minimum 1-week washout period between conditions. The participants were tested on 4 separate occasions. Because all the participants completed both conditions, the participant characteristics for CON and INT were identical. Because prior data were not available to support a formal a priori power calculation for the present acute metabolic outcomes, the study was designed as an exploratory crossover study. A sample size of 14 participants was considered appropriate because pilot studies commonly use approximately 12 participants per condition when effect-size estimates are unavailable, and the crossover design further strengthened efficiency by allowing each participant to complete both exercise conditions.

Exercise Protocols

Constant speed walking (CON): Participants walked on a motorized treadmill for 60 continuous minutes at an intensity corresponding to approximately 45% of their individual VO_2 peak. Interval walking (INT): Participants walked for 60 minutes using a repeating cycle of 3 consecutive 3-min stages: slow (30% VO_2 peak), moderate (45% VO_2 peak), and fast (60% VO_2 peak). This cycle was repeated throughout the 60-min session. The INT protocol was designed to match the mean intensity of the CON protocol (45% VO_2 peak), ensuring that total work remained consistent across conditions while isolating speed variation as the primary independent variable.

Visit 1: Baseline and VO_2 Peak Testing

Body mass (kg) and height (cm) were recorded using a calibrated scale and stadiometer. Resting blood pressure was assessed via automated sphygmomanometer (Accutor, Mindray Inc., NJ). Resting and exercise heart rate were continuously monitored using a Polar heart rate strap (Polar Electro Inc., NY). BMI was calculated as weight (kg) / height (m)². Peak oxygen consumption (VO_2 peak) was assessed via a graded treadmill exercise test using indirect calorimetry (Parvo Metabolic System, True Max 2400, Sandy, UT). The treadmill began at 2.0 miles per hour (mph) and increased by 0.5 mph every 60 seconds until volitional exhaustion. Expired O_2 was analyzed continuously and averaged every 10 seconds.

Visit 2: Determination of Walking Speeds

Individual treadmill speeds corresponding to 30%, 45%, and 60% of each participant's VO_2 peak were determined. Speed was gradually adjusted in increments of 0.2 to 0.5 mph until target intensities were confirmed by indirect calorimetry.

Visits 3 and 4: Experimental Exercise Sessions

All the participants reported to the laboratory between 7:00 and 8:00 following a 12-hour overnight fast with ad libitum water intake permitted. Resting metabolic rate (RMR) was measured for 30 min using the ventilated canopy method (Parvo Metabolic System, True Max 2400). An intravenous catheter was inserted in a forearm vein for serial blood sampling. Blood samples (3 mL) were obtained at rest and every 10 min during exercise (7 total draws). Heart rate was monitored continuously throughout each session. Energy expenditure was assessed throughout exercise by indirect calorimetry using the Parvo Metabolic System (True Max 2400, Sandy, UT). Expired gases were collected continuously and averaged at regular intervals during each walking session. Fat-derived energy expenditure was estimated from gas-exchange measurements obtained during exercise, and mean net energy expenditure from fat was expressed in kcal/min for each condition. These values were then used to compare the metabolic responses to constant speed walking and interval walking across the 60-min exercise session. After the washout period, the participants returned for Visit 4. Those who performed CON at Visit 3 performed INT at Visit 4 and vice versa.

Blood Sample Processing

All blood samples were immediately placed on ice following collection. After each session, samples were centrifuged for 10 min to separate plasma. Plasma aliquots were stored at −80°C until analysis. Plasma glycerol concentrations were quantified using a colorimetric glycerol assay kit (Glycerol Colorimetric Assay Kit, #10010755, Cayman Chemical, Ann Arbor, MI).

Statistical Analysis

All the data are expressed as mean ± SD. A two-way repeated-measures ANOVA (condition × time) was used to assess differences in time-course outcomes, including fat-derived energy expenditure and plasma glycerol, between INT and CON. Session-averaged net energy expenditure from fat was also compared between conditions using a paired *t* test. Tukey's *post hoc* test was applied when significant main effects or interactions were detected. Statistical significance was set at $P < 0.05$. All analyses were performed using SigmaPlot version 16.

RESULTS

Participant Characteristics

The sample consisted of 14 participants. Mean age was 22.9 ± 2.9 years, height 166.4 ± 8.5 cm, body mass 63.9 ± 10.5 kg, BMI 22.9 ± 2.3 kg/m², and VO_2 peak 40.3 ± 7.8 mL/kg/min. All the participants self-reported no regular exercise routine. Participant characteristics are presented in Table 1. RMR was comparable between sessions (CON: 1428 ± 245 kcal/day; INT: 1459 ± 277 kcal/day) with no significant difference between the conditions (P > 0.05).

Table 1. Descriptive Data of the Participants (Mean ± SD; N = 14).

Variable	CON (N = 14)	INT (N = 14)
Age (yr)	22.9 ± 2.9	22.9 ± 2.9
Height (cm)	166.4 ± 8.5	166.4 ± 8.5
Body Mass (kg)	63.9 ± 10.5	63.9 ± 10.5
BMI (kg/m²)	22.9 ± 2.3	22.9 ± 2.3
VO_2 peak (mL/kg/min)	40.3 ± 7.8	40.3 ± 7.8
RMR (kcal/day)	1428 ± 245	1459 ± 277

Note: **CON** = Constant Speed Walking; **INT** = Interval Walking. Identical values reflect the within-subject crossover design. All participants completed both conditions.

Fat-Derived Energy Expenditure

The rate of fat-derived energy expenditure (kcal/min) over time during both conditions is presented in Figure 1. Both INT and CON conditions showed a gradual increase in fat use across the 60-min session. However, there was no significant difference between the conditions at any time point. Mean net energy expenditure from fat after subtracting resting fat-derived energy expenditure was 2.91 ± 1.01 kcal/min for INT and 2.70 ± 0.81 kcal/min for CON (Figure 2), with no significant difference between the conditions.

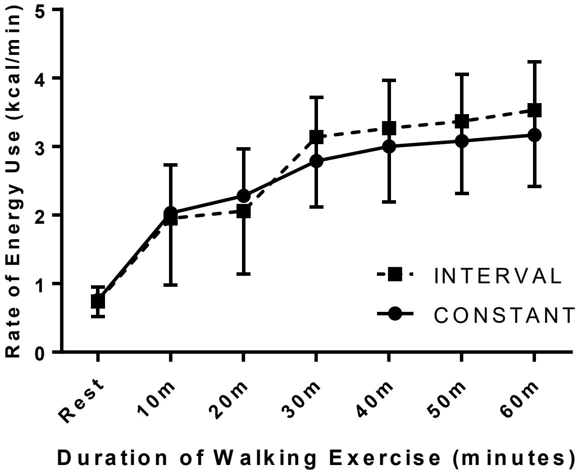

Figure 1. The Rate of Fat-Derived Energy Expenditure (kcal/min) during 60 min of Walking in the Constant Speed (CON) and Interval (INT) Conditions. Values are Mean ± SD (N = 14; within-subject crossover design).

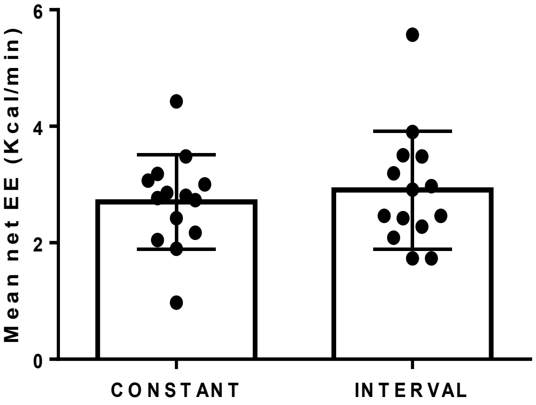

Figure 2. Mean Net Energy Expenditure (EE) from Fat (kcal/min) during the 60-min Walking Sessions for CON (2.70 ± 0.81 kcal/min) and INT (2.91 ± 1.01 kcal/min). Values are Mean ± SD (N = 14; within-subject crossover design). No Significant Difference Between Conditions.

Plasma Glycerol

Plasma glycerol concentrations increased progressively over the course of exercise in both conditions (Figure 3). No significant difference in glycerol concentration was observed between INT and CON at any time point. However, within-condition comparisons (Figure 4) revealed that glycerol levels at 50 and 60 min were significantly elevated compared to those at 10 min in both conditions ($P < 0.05$), indicating progressive lipolysis with increasing exercise duration in both conditions.

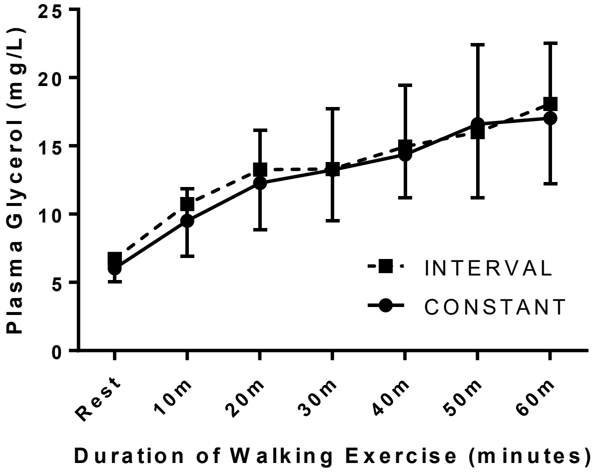

Figure 3. Plasma Glycerol Concentrations (mg/L) at Rest and During 60 min of Walking in CON and INT Conditions. Values are Mean ± SD (N = 14; within-subject crossover design).

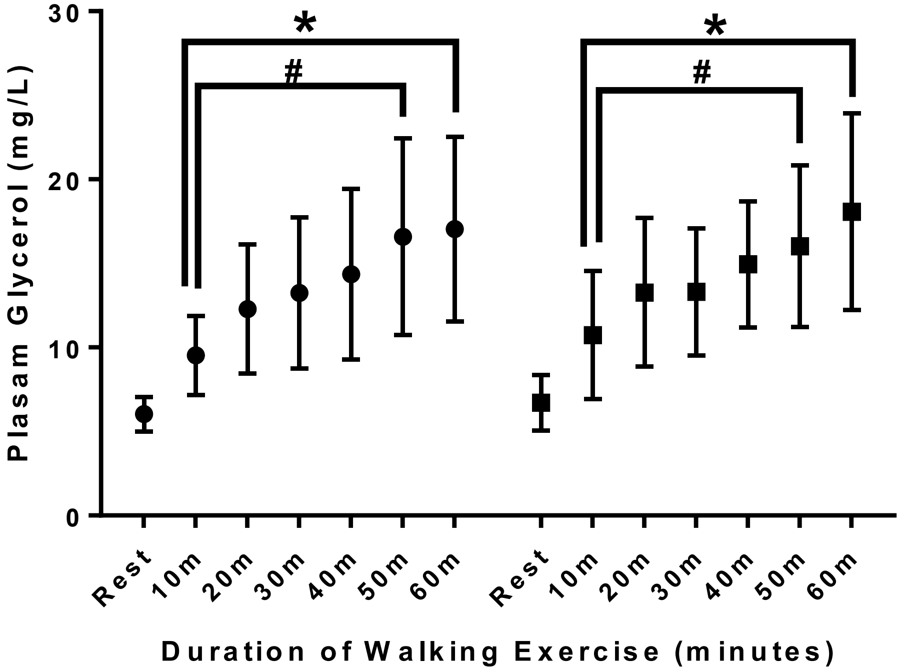

Figure 4. Within-Condition Plasma Glycerol Concentrations (mg/L) Over Time During CON and INT Walking. Closed Circles (●) Represent CON; Closed Squares (■) Represent INT. * $P < 0.05$ vs. 10 min within CON; # $P < 0.05$ vs. 10 min within INT. Values are Mean ± SD (N = 14; within-subject crossover design).

DISCUSSION

The primary finding of this study is that a single 60-min bout of interval walking did not produce significantly greater fat-derived energy expenditure compared to continuous constant speed walking in healthy sedentary adults. Despite the INT condition including higher-intensity intervals (up to 60% VO_2 peak), mean net energy expenditure from fat was comparable between the conditions. These results are partially consistent with those of Venables and Jeukendrup, who reported that continuous exercise at 44% VO_2 max in obese adults produced fat oxidation rates similar to or greater than interval exercise at 65% VO_2 max (23). Similarly, Romijn et al. found that peak fat oxidation in endurance athletes occurred at 65% VO_2 max, with lower rates at both 25% and 85%, suggesting that the intermediate intensities used in the present study may not have been sufficient to differentially activate lipolytic pathways between conditions (20).

Importantly, both conditions demonstrated a significant time-dependent increase in plasma glycerol from 10 to 50–60 min of exercise. Glycerol is the backbone of triglycerides released during lipolysis and serves as a reliable indicator of adipose tissue lipolysis (12). This pattern is consistent with prior work showing that the rate of adipose tissue lipolysis increases progressively with exercise duration at low-to-moderate intensities (12,24). The increase in glycerol over time likely reflects the progressive catecholamine-mediated activation of hormone-sensitive lipase (HSL) and the resulting increase in triglyceride hydrolysis (2,12).

The regulation of lipolysis involves coordinated enzymatic and hormonal signaling. HSL is phosphorylated and translocated from the cytosol to the lipid droplet surface within adipocytes, a process that is facilitated by phosphorylation of the scaffolding protein perilipin via Protein Kinase A (PKA) (12). Once perilipin is phosphorylated, HSL can access and hydrolyze intracellular triglycerides, yielding two unesterified fatty acid molecules and one monoglyceride, which is subsequently cleaved into glycerol and a fatty acid by monoglyceride lipase (12). Catecholamines (epinephrine and norepinephrine) stimulate this cascade by acting on beta-adrenoceptors, whose stimulation increases with exercise intensity (2,8). At rest, lipolysis is tonically suppressed by alpha-adrenoceptor activity; during exercise, elevated plasma catecholamines shift this balance toward beta-adrenoceptor stimulation and increased lipolysis (2). While the INT protocol in the present study reached a peak intensity of 60% VO_2 peak, this may not have exceeded the metabolic threshold required to trigger the significantly higher catecholamine surge typically observed in high-intensity interval training (HIIT). Prior research suggests that alpha-adrenoceptor-mediated inhibition of lipolysis may be more effectively overridden at higher intensities (typically >75% VO_2 peak), which may explain why the intermittent 60% VO_2 peak bouts did not elicit a superior glycerol response compared to the constant 45% VO_2 peak condition (2,8).

The similar rates of fat-derived energy expenditure between INT and CON suggest that exercise duration—rather than speed variation per se—may be the primary driver of fat metabolism during low-to-moderate intensity walking. This interpretation aligns with earlier work showing that walking at extended durations at low intensities in a fasted state significantly elevates FFA and glycerol concentrations in plasma (1,20). These observations have practical implications for designing walking programs for weight management: accumulating sufficient duration of walking, even at a single moderate speed, may be as effective as speed-varied interval programs for promoting fat oxidation in sedentary individuals.

Beyond these physiological findings, the similar metabolic responses observed during INT and CON suggest that exercise prescription for sedentary adults may be individualized according to preference, tolerability, and perceived enjoyment. Affective responses to exercise are influenced by exercise intensity, and exercise perceived as excessively demanding may reduce pleasure and potentially undermine adherence in insufficiently active individuals (7). Conversely, interval-based exercise may be perceived as more enjoyable than continuous exercise in some settings, possibly because variation in intensity reduces monotony (4). Because both walking modalities in the present study elicited similar fat-derived energy expenditure, clinicians and fitness professionals may allow individuals to choose the walking format they find most engaging and sustainable. This flexibility may be particularly important for promoting long-term participation in walking-based exercise programs.

Limitations in this Study

Several limitations of this study should be acknowledged. The sample size was relatively small (N = 14) and consisted of young, healthy adults with normal BMI, limiting generalizability to older populations or those with metabolic disorders. The study did not include a dietary control condition, and all measurements were acute (single session), precluding inferences about chronic adaptations. Additionally, the INT protocol did not include truly high-intensity intervals (e.g., above 75% VO_2 peak), which may have limited its fat-oxidation stimulus relative to more intense protocols used in other studies.

Future investigations should examine the effects of INT and CON in broader populations (e.g., individuals with overweight/obesity, older adults), over longer training periods, and with dietary controls. The role of sex and hormonal differences in modulating fat utilization responses to these protocols also warrants further study. Additionally, integrating measures of intramuscular triglyceride oxidation alongside blood markers would provide a more complete picture of substrate utilization.

CONCLUSION

In healthy sedentary adults, a single 60-min session of interval walking did not produce significantly greater fat-derived energy expenditure than constant speed walking. Both modalities produced a time-dependent increase in plasma glycerol, consistent with progressive lipolysis driven by exercise duration rather than speed variation. These findings suggest that exercise duration is an important mediator of fat metabolism during low-to-moderate intensity walking and that both interval and continuous walking may be similarly effective for promoting lipid mobilization in healthy sedentary individuals.

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Physical Fitness and Self-Esteem Among Physically-Active Below-Knee Amputees Compared to Their Inactive Peers

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ABSTRACT

Abu Romman Y, Al Oran H, Al-Rahamneh H. Physical Fitness and Self-Esteem among Physically-active Below-Knee Amputees compared to their inactive peers. The purpose of this study was to assess muscular strength, balance, flexibility, and self-esteem among physically active individuals with below-knee amputation compared to their physically inactive peers. The sample consisted of 9 participants with below-knee amputation (age 43.22 ± 17.16 years). The data were collected through testing procedures and analyzed statistically using means, standard deviations, and the Mann–Whitney Test. Knee extension of the right leg was better ($P = 0.050$) and balance, flexibility, and self-esteem have higher mean values among the physically active compared to their physically inactive peers. Additionally, the participants with congenital amputation demonstrated better results in balance and self-esteem compared to those with acquired amputation ($P < 0.05$). The findings indicate that physical activity has a positive impact on both physical and psychological variables among individuals with a lower-limb amputation, and the type of amputation (congenital vs. acquired) plays a significant role in the outcomes.

Key words: Balance, Congenital, Lower-Limbs Amputees, Physically-Active, Psychological

INTRODUCTION

Amputation is defined as the surgical removal of part or all of a limb as a result of trauma, disease, or congenital deformity. In many cases, amputation is performed as a life-saving procedure to prevent the spread of infection or to remove nonfunctional tissue, such as in cases of gangrene, severe injury, or congenital abnormalities. Regardless of whether amputees engage in physical activity, amputation leaves lasting physical and psychological effects. However, the severity of these effects varies depending on the individual's ability to adapt, regain independence, and return to daily life activities. In this context, self-esteem plays a critical role, given that it may serve as a motivating factor that supports rehabilitation and continuity of life, or conversely, as a barrier that limits daily functioning (8). One of the most important factors supporting independence among amputees is the use of prosthetic limbs that significantly contributes to restoring mobility and facilitating reintegration into daily life (8).

Discussions surrounding individuals with limb amputation are often dominated by emotional perspectives that focus on their needs, aspirations, and perceived deficiencies. In general, disability can be defined as a condition in which an individual is restricted from fully utilizing one or more physical, mental, or sensory abilities (1). The disability may be congenital or acquired at different stages of life. Physical disability, in particular, refers to permanent bodily impairment that affects an individual's ability to carry out daily activities, such as amputation, fracture, or paralysis (1). This study specifically addresses individuals with lower limb amputation that focus on the individual's ability to perform daily life activities and the psychological and physical impact of amputation following injury (1).

Professionals working in the field of disability emphasize the necessity of physical activity due to its positive physical and psychological outcomes. Several sports are particularly suitable for individuals with lower limb amputation, such as swimming, javelin throw, shot put, tennis, table tennis, golf, and discus throw (8).

Working with individuals with amputation is considered a humanitarian responsibility that requires accurate awareness and understanding, as well as appropriate guidance and support to enable the individuals to benefit from their diverse abilities. In this context, physical education plays a fundamental role in their lives. Participation in sports and physical activities helps the individuals with amputation to overcome negative emotions resulting from disability, whether the amputation occurred during childhood or as a result of sudden trauma or illness (1). Consequently, physical activity has become an essential component of healthy living for individuals with disabilities, as it represents an effective means of physical, psychological, and social rehabilitation. Through sports, individuals with disabilities can develop their physical capabilities, motor skills, and overall functional and/or mental well-being (1).

Research indicates that individuals who are often forced to undergo lower or upper limb amputation, which subsequently leads to multiple challenges result in psychological distress, low self-esteem, and pessimistic perceptions toward future life circumstances. Yet, despite these difficulties, many amputees strive to adapt and continue their lives while coping with their new realities.

Following amputation, individuals frequently experience additional challenges related to the use of prosthetic limbs, the weakness in the residual limb muscles, and the impaired balance and trunk instability. Moreover, the intact contra-lateral limb may develop secondary problems due to compensatory overuse. Some amputees refuse to use prosthetic limbs, while others demonstrate varying functional outcomes depending on the duration of prosthetic use.

Accordingly, the researcher sought to investigate the levels of selected physical fitness components, namely muscular strength, balance, and flexibility as well as the self-esteem among physically active and inactive individuals with below-knee lower limb amputation.

Significance of this Study

The significance of this study can be summarized as follows. It is considered one of the first studies in Jordan to examine both the physical and the psychological aspects of individuals with lower limb amputation. This study provides feedback to relevant authorities regarding the use and effectiveness of prosthetic limbs, and it offers insight into the levels of physical fitness and self-esteem among individuals with lower limb amputation. Also, this study highlights the importance and benefits of participating in physical activities for individuals with amputation.

Objectives of the Study

This study is designed to assess the differences in muscular strength, balance, flexibility, and self-esteem among individuals with below-knee lower limb amputation among physically active individuals compared to their inactive peers as well as the differences in muscular strength, balance, flexibility, and self-esteem among individuals with congenital below-knee lower limb amputation compared to those with acquired amputation.

METHODS

Subjects

The study sample consisted of 9 participants (7 males and 2 females) with a below-knee lower limb amputation. Their mean age was 43.22 ± 17.16 years. Also, 5 of the 9 participants were physically active and 4 were not.

Procedures

The Rosenberg Self-Esteem Scale (11) was used to assess the participants' levels of self-esteem. The scale consists of 10 items with responses recorded on a four-point Likert scale: *strongly agree, agree, disagree,* and *strongly disagree*. For positively worded items (Items 1, 2, 4, 6, and 7), scoring was assigned as follows: Strongly agree = 3; Agree = 2; Disagree = 1; Strongly disagree = 0, and for negatively worded items (Items 3, 5, 8, 9, and 10), scoring was reversed as follows: Strongly agree = 0; Agree = 1; Disagree = 2; Strongly disagree = 3. The total self-esteem score was calculated by summing item scores with higher scores indicating higher levels of self-esteem. Muscular strength was assessed using isokinetic testing, including knee flexion and extension measurements that were performed with the Biodex System 3 dynamometer. During the test, the participants exerted maximal force against the resistance provided by the device, which recorded the torque generated by the tested muscle groups.

Isometric muscle strength was measured during knee extension, starting from a joint angle of 90° and during knee flexion starting from 83°. The testing angles were determined based on a pilot study using 1 participant. The Biodex device generated resistance in both movement directions that allowed accurate assessment of muscle strength in the tested joints. Muscular strength was measured for both the amputated limb and the intact limb of the participants using the Biodex System.

Balance was assessed using the Berg Balance Scale (4), which consists of 14 functional tasks. Each task is scored on a scale ranging from 0 to 4, where 0 represents the lowest level of performance and 4 represents the highest level. The maximum total score is 56 points. Scores between 41 and 56 indicate independent mobility, 21 to 40 indicate the need for assistance during movement, and 0 to 20 indicate a high risk of falls and the need for wheelchair use. Flexibility was assessed using the sit-and-reach test. A calibrated flexibility box was placed on the floor and stabilized against a wall. The zero point of the test was set at 23 cm. The participants were instructed to sit on the floor with knees fully extended and feet placed flat against the front of the box. With arms extended forward, the participants bent the trunk forward as far as possible, reaching toward the measurement scale. The distance reached was recorded as the flexibility score (2). This test was selected due to its simplicity and validity in assessing trunk and hamstring flexibility.

Statistical Analyses

Descriptive statistics, including means, standard deviations, and the Mann–Whitney U Test, which was used due to the non-normal distribution of the data to determine whether there were differences between groups (i.e., physically active vs. inactive and acquired vs. congenital).

RESULTS

Means ± SD values for flexibility, strength, balance, and self-esteem are presented in Table 1.

Table 1. Means ± SD for Flexibility, Strength, Balance, and Self-Esteem of Both Physically Active and Inactive.

Variable	Physically Active (N = 5)	Physically Inactive (N = 4)
Flexibility (cm)	25.80 ± 7.82	25.50 ± 5.80
Right Leg Strength		
Right Knee Extension (kg)	23.15 ± 6.47	15.05 ± 2.77
Right Knee Flexion (kg)	14.96 ± 2.56	23.63 ± 2.59
Total Balance Score (out of 56)	50.60 ± 6.54	47.50 ± 2.65
Total Self-Esteem Score (out of 30)	26.40 ± 2.61	22.00 ± 1.41

The results of the means showed better values for physically active than their inactive peers in knee extension, balance and self-esteem. However, similar mean values were observed in flexibility between the 2 groups and the inactive participants showed better means values in knee flexion. The Mann–Whitney U Test was used to examine the differences in flexibility, muscular strength, balance, and self-esteem between the physically active with lower limbs amputees compared to their physically inactive peers. The results are shown in Table 2.

Table 2. Mann–Whitney U Test for Flexibility, Muscular Strength, Balance, and Self-Esteem Between Physically Active and Their Inactive Peers.

Variable	Physical Activity	Sum of Ranks	n	Mean Rank	Z	P-value
Flexibility (cm)	Active	25.50	5	5.10	-0.12	0.902
	Inactive	19.50	4	4.88		
Right Leg Strength extension (kg)	Active	33.00	5	6.60	-1.96	0.050*
	Inactive	12.00	4	3.00		
Right Leg Strength flexion (kg)	Active	15.00	5	3.00	-2.45	0.014*
	Inactive	30.00	4	7.50		
Balance (out 56)	Active	27.00	5	5.40	-0.49	0.623
	Inactive	18.00	4	4.50		
Self-Esteem (out of 30)	Active	32.50	5	6.50	-1.88	0.059
	Inactive	12.50	4	3.13		

The Mann-Whitney U Tests results indicate a significant difference in knee extension for physically active than their inactive peers ($P < 0.05$). However, the opposite was observed in knee flexion ($P < 0.05$). No significant differences were observed in flexibility, balance and self-esteem ($P > 0.05$), although better means values in balance and self-esteem were observed for the physically active than their inactive peers.

The Mann–Whitney U Test was used to examine the differences in flexibility, muscular strength, balance, and self-esteem between the congenital lower limbs amputees compared to their acquired peers. The results are shown in Table 3.

Table 3. Mann–Whitney U Test for Flexibility, Muscular Strength, Balance, and Self-Esteem Between Congenital Lower Limbs Amputee and Their Acquired Peers.

Variable	Means ± SD	Cause of Amputation	Sum of Ranks	n	Mean Rank	Z	P-value
Flexibility (cm)	28.76 ± 9.45	Congenital	18.50	3	6.17	0.90	0.381
	24.17 ± 5.04	Acquired	26.50	6	4.42		
Right Leg Strength Extension (kg)	21.58 ± 7.80	Congenital	18.00	3	6.00	0.77	0.439
	18.53 ± 6.26	Acquired	27.00	6	4.50		
Right Leg Strength Flexion (kg)	15.57 ± 2.81	Congenital	10.00	3	3.33	1.29	0.197
	20.43 ± 5.48	Acquired	35.00	6	5.83		
Balance (out of 56)	55.33 ± 1.15	Congenital	24.00	3	8.00	2.33	0.020*
	46.17 ± 2.93	Acquired	21.00	6	3.50		
Self-Esteem (out of 30)	27.67 ± 1.15	Congenital	23.00	3	7.67	2.11	0.034*
	22.83 ± 2.32	Acquired	22.00	6	3.67		

Statistically significant differences were observed in balance ($P = 0.020$), and self-esteem ($P = 0.034$) for congenital amputees compared to those with acquired amputees. However, no significant differences were observed in flexibility and leg strength in extension and flexion modes between those with congenital lower limbs amputation compared to those with acquired peers (P > 0.05).

DISCUSSION

Physical activity improves balance, leg extension, and self-esteem among lower limbs amputees compared to their physically-inactive peers. These findings are in agreement with Nolan's findings (10) who observed that active transtibial demonstrated greater peak hip torques (Nm/kg) for all conditions and speeds compared to inactive transtibial amputees. In addition, Dupuis et al. (6) indicated in their review article that combined strength or balance and aerobic exercises 1 to 3 times per week improved balance, walking speed, walking endurance, and transfer ability in adults with low limbs amputees.

The recent findings of this study showed high self-esteem for physically-active amputees (26.4) compared to a moderate self-esteem level of their inactive peers (22.0). Rosenberg (1965) reported that self-esteem of 0-15 points indicate low level, 16-25 points indicate moderate level, and 25-30 points indicate high level of self-esteem. These findings are in agreement with Wetterhahn et al. (12) results that indicated a positive relationship was found between regular participation in physical activity and body image among lower limb amputees. The American College of Sport Medicine (2023) indicated that physical activity reduced depression and anxiety, increased maximal oxygen uptake that is a gold measure of cardiorespiratory system. ACSM (3) and Costill et al. (5) also showed that physical activity reduced falls among elderly persons, which is the result of improved strength and balance.

The results of the current study showed that congenital amputees have better values in flexibility, balance, self-esteem, and leg extension strength compared to those with acquired amputation. These findings are in agreement with Montesinos-Magraner et al. (9). The authors indicate that acquired amputees (such as sever traumas) could be related to higher anxiety, depression, frustration, and hostility; whereas, those with congenital amputation do not consider limb loss as a disability or a disease (7).

CONCLUSIONS

Flexibility, knee extension, balance, and self-esteem were better among the physically active individuals than the inactive persons with low limbs amputation. Self-esteem and balance were better among the congenital persons with low limbs amputation compared to those with congenital lower limbs amputation. The findings support the importance of adopting physically life style for amputees.

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Relationship Between Resting Heart Rate and Chest Expansion in Community-dwelling Older Adults: Association with Pulmonary Function

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ABSTRACT

Pia la Y, Ittinirundorn S, Tongtako W. Aging affects both the cardiovascular system and the respiratory system by altering heart rate regulation and reducing thoracic mobility. This study investigated the relationship between resting heart rate, chest expansion, and pulmonary function in older adults. Twenty-six older adults participated in this cross-sectional correlational study. Resting heart rate, chest expansion at 3 thoracic levels (i.e., the axillary line, the xiphoid process, and the 10th rib), and forced vital capacity (FVC) were measured. Resting heart rate was significantly negatively correlated with chest expansion at the axillary line ($r = -0.899$), xiphoid process ($r = -0.883$), and the 10th rib ($r = -0.835$), all $P < .001$. Chest expansion was significantly positively correlated with FVC at all levels ($r = 0.917–0.969$, $P < .001$). Higher resting heart rate is associated with reduced chest expansion that suggest diminished thoracic mobility may contribute to cardiovascular strain and lower pulmonary function in older adults.

Key Words: Chest Expansion, Elderly, Forced Vital Capacity

INTRODUCTION

Aging is associated with progressive physiological decline in both the cardiovascular system and the respiratory system, which leads to a decrease in functional capacity and an increase in susceptibility to chronic diseases in older adults (6,19,23). One of the common cardiovascular changes observed with aging is alteration in autonomic regulation that may result in elevated resting heart rate (RHR), reflecting a decrease in parasympathetic activity and an increase in cardiovascular workload (8,14). Resting heart rate is widely recognized as an important indicator of cardiovascular health and has been associated with morbidity, mortality, and reduced physical fitness in older adults (4,21).

Aging affects respiratory mechanics, which is problematic. Structural changes in the thoracic cage, decreased elasticity of lung tissue, weakening of the respiratory muscles, and calcification of costal cartilage contribute to reduced chest wall compliance and diminished thoracic expansion (18). Chest expansion is a simple clinical measure used to assess thoracic mobility and respiratory muscle function (11,22). Reduced chest expansion may indicate impaired ventilator mechanics and decreased pulmonary efficiency that can negatively affect daily activities and quality of life in older adults.

Chest expansion has been positively associated with pulmonary performance because adequate thoracic mobility is necessary for effective lung inflation (2,7). In elderly individuals, decreased chest expansion may therefore reflect both musculoskeletal stiffness and compromised respiratory capacity (2,16). In fact, several previous studies (1,5,20) have shown that respiratory function decreases with aging, including reductions in lung volumes such as forced vital capacity (FVC).

Although cardiovascular and respiratory aging are closely interconnected, limited research has examined the relationship between resting heart rate and chest expansion in older adults. Understanding this association may provide insight into the interaction between cardiovascular demand and respiratory mechanical limitations in aging populations. Furthermore, examining the relationship between chest expansion and pulmonary function may help clarify the clinical significance of thoracic mobility assessment in elderly care. Hence, the purpose of this study was to investigate the relationship between resting heart rate and chest expansion at 3 thoracic levels (i.e., the axillary line, the xiphoid process, and the 10th rib) in older adults, and to determine the association between chest expansion and forced vital capacity.

METHODS

Subjects

The study protocol was approved by the Research Ethics Review Committee for Research Involving Human Subjects at Chulalongkorn University. The sample size of the subjects was determined by the Bujang and Baharum (3) with an alpha error of 0.05 and a power of 0.80, baseline correlation (R0) of 0, and an alternative correlation (R1) of 0.7. A minimum of 24 subjects were required for this study. The study included 26 older adults aged 18 to 65 years who live in Bangkok, Thailand. Eligible participants were community-dwelling older male and female adults aged 60 to 75 years who had not engaged in regular exercise (defined as fewer than 2 sessions per week) during the previous 6 months. Individuals with a history of cardiovascular disease, respiratory disorders, and/or neuromuscular impairments were excluded. All the participants were required to be independently mobile without assistive devices and to provide written informed consent prior to enrollment.

Procedures

Once the participants met the criteria, appointments were scheduled for testing and data collection. Written informed consent was obtained from all the participants before their involvement. The participants underwent a 1-hr assessment that included physiological characteristics, pulmonary functions, and chest expansion.

Physiological Data Testing

After a 10-min rest period, a digital sphygmomanometer (GE Dinamap CARESCAPE, V100, USA.) was used to measure blood pressure (mmHg) and heart rate (bpm). A body composition analyzer (BIA) (OMRON, HBF-375, Japan) was also used to measure body weight (kg), body fat (%) and body mass index (BMI) (kg/m^2).

Pulmonary Function Testing

The projected values in liters of FVC were measured using a computerized spirometer (SpirobankG) in accordance with the American Thoracic Society's pulmonary function test recommendations. The participants sat on a chair while wearing a nasal clip. They performed 3 cycles of slow, normal breathing before demonstrating forced inspiration and expiration and then returned to normal breathing.

Chest Expansion Testing

Chest expansion was measured with the participants seated upright with their hands placed on their hips. Then, the participants were instructed to breathe normally for 2 to 3 breaths before performing maximal expiration followed by a maximal inspiration when ready. The investigator measured chest expansion using a measuring tape at 3 thoracic levels, the upper thoracic level at the axillary line (midpoint between the 2nd and the 4th ribs), the middle thoracic level at the xiphoid process (midpoint between the 4th and 6th ribs), and the lower thoracic level at the 10th rib. Measurements were performed twice at each level with a 1-min rest interval between each level. The 2 values obtained at each level were averaged and recorded in centimeters (cm) as the chest expansion value for that site.

Statistical Analyses

The data were analyzed using the SPSS version 28 for Windows (SPSS Inc., Chicago, USA). Pearson's correlation was used to analyze the relationship among RHR, chest expansion, and FVC. Differences (or Associations?) were considered significant at $P < 0.05$. Descriptive statistics are presented as mean ± SD.

RESULTS

The physiological characteristics of the participants are presented in Table 1. A total of 26 older adults were enrolled in the study, comprising 7 males and 19 females, with a mean age of 65.00 ± 3.22 years. The mean body weight was 60.42 ± 5.67 kg, mean height was 160.19 ± 5.64 cm, and mean body mass index (BMI) was 23.48 ± 0.54 kg/m^2. The average resting heart rate was 83.38 ± 1.55 beats/min, while the mean systolic and diastolic blood pressures were 126.88 ± 1.68 mmHg and 80.26 ± 1.25 mmHg, respectively, indicating that the participants generally exhibited stable physiological and cardiovascular profiles.

Table 1. Physiological Characteristics Data.

Variables	**Older Adults** **(N = 26)**
Age (year)	65.00 ± 3.22
BW (kg)	60.42 ± 5.67
Height (cm)	160.19 ± 5.64
BMI (kg/m^2)	23.48 ± 0.54
HR ($beats \cdot min^{-1}$)	83.38 ± 1.55
SBP (mmHg)	126.88 ± 1.68
DBP (mmHg)	80.26 ± 1.25

Data are presented as mean ± SD. **BW** = Body Weight, **HR** = Heart Rate, **BMI** = Body Mass Index, **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure

Table 2 summarizes the respiratory variables of the participants. The mean forced vital capacity (FVC) was 2.48 ± 0.31 L. Mean chest expansion values were 88.95 ± 1.77 cm at the axillary line, 83.76 ± 1.37 cm at the xiphoid process, and 82.81 ± 1.41 cm at the 10th rib level.

Table 2. The Mean and Standard Deviation of Respiratory Variables.

Variables	**Older Adults** **(N = 26)**
FVC (L)	2.48 ± 0.31
CHEST EXPANSION	
Axillary Line (cm)	88.95 ± 1.77
Xiphoid Process (cm)	83.76 ± 1.37
Tenth Rib (cm)	82.81 ± 1.41

Data are presented as mean ± SD. **FVC** = Forced Vital Capacity

The correlations among resting heart rate, chest expansion, and forced vital capacity (FVC) are presented in Table 3. Resting heart rate demonstrated significant strong negative correlations with chest expansion at all 3 thoracic measurement sites, including the axillary line ($r = -0.899$, $P < .001$), xiphoid process ($r = -0.883$, $P < .001$), and 10th rib level ($r = -0.835$, P

$< .001$). In contrast, FVC showed significant strong positive correlations with chest expansion at each thoracic level: axillary line ($r = 0.969$, $P < .001$), xiphoid process ($r = 0.955$, $P < .001$), and tenth rib level ($r = 0.917$, $P < .001$).

Table 3. Association Between Resting Heart Rate and Pulmonary Variables.

Chest Expansion	Correlation	Resting Heart Rate	FVC
Axillary Line (cm)	Coefficient value	-0.899	0.969
	P value	<0.001*	<0.001*
	Relationship	Very high correlation	Very high correlation
Xiphoid Process (cm)	Coefficient value	-0.883	0.955
	P value	<0.001*	<0.001*
	Relationship	Very high correlation	Very high correlation
Tenth Rib (cm)	Coefficient value	-0.835	0.917
	P value	<0.001*	<0.001*
	Relationship	Very high correlation	Very high correlation

*$P < 0.05$

DISCUSSION

The present study demonstrated significant strong negative correlations between resting heart rate and chest expansion at all 3 thoracic measurement levels in the older adults. Specifically, higher resting heart rate was associated with lower chest expansion at the axillary line, xiphoid process, and the 10th rib. In addition, chest expansion at all measured levels showed strong positive correlations with forced vital capacity, which indicated that greater thoracic mobility is associated with enhanced pulmonary function.

These findings suggest an important physiological interaction between cardiovascular regulation and respiratory mechanics in aging individuals. The significant negative correlation observed between resting heart rate and chest expansion in the present study is consistent with previous evidence demonstrating that aging is accompanied by progressive autonomic dysregulation and declining respiratory mechanical efficiency. Elevated resting heart rate in older adults may reflect reduced vagal modulation, sympathetic predominance, and increased cardiovascular strain, as reported by Grässler et al. (10) and Olivieri et al. (15).

Similarly, the observed reduction in chest expansion is supported by earlier studies indicating that aging leads to structural and functional changes in the respiratory system. Lee et al. (13) and Sharma and Goodwin (18) reported that thoracic cage stiffness increases with age due to calcification of costal cartilage, reduced intervertebral mobility, weakening of the respiratory musculature, and loss of elastic recoil in the connective tissues, all of which contribute to diminished thoracic compliance and reduced ventilatory capacity. These age-related alterations may explain the decreased chest wall mobility observed in the present study.

The strong negative association between resting heart rate and chest expansion may be explained by decreased thoracic mobility that leads to less efficient ventilation. When chest wall expansion is restricted, respiratory efficiency decreases, which potentially increases the physiological demand on the cardiovascular system to maintain oxygen delivery (9,18). As a compensatory mechanism, resting heart rate may increase to preserve tissue oxygenation. This interaction highlights the functional integration between the respiratory and cardiovascular systems in the elderly population.

The strong positive correlation observed between chest expansion and FVC in the present study supports the validity of chest expansion as a clinically meaningful indicator of pulmonary performance. This finding is consistent with previous studies demonstrating that greater thoracic mobility is associated with higher lung volumes and enhanced respiratory capacity. Lanza et al. (12) reported that chest wall mobility was significantly correlated with FVC, indicating that individuals with greater chest wall excursion exhibit better pulmonary function. Similarly, Reddy et al. (17) found that upper and lower chest expansion measurements were positively associated with lung function parameters, including FVC, supporting the use of chest expansion as a simple indirect assessment of respiratory performance.

These findings have both practical clinical implications. Measurement of chest expansion is inexpensive, noninvasive, and easy to perform in community and clinical settings. It may serve as a useful screening tool to identify elderly individuals at risk of declining cardiopulmonary function. Early detection of reduced thoracic mobility could help guide interventions such as breathing exercises, thoracic mobility training, respiratory muscle strengthening, and aerobic conditioning programs aimed at improving overall functional health.

Limitations in this Study

Several limitations should be acknowledged. First, the sample size was relatively small, which may limit generalizability of the findings. Second, the cross-sectional design prevents determination of causal relationships between resting heart rate and chest expansion. Third, other factors influencing cardiopulmonary function, such as physical activity level, medication use, and comorbidities were not controlled in this study.

CONCLUSIONS

This study demonstrates that resting heart rate is significantly negatively associated with chest expansion in older adults, while chest expansion is positively associated with pulmonary function. These findings emphasize the interconnected decline of cardiovascular and respiratory systems with aging and support the clinical relevance of chest expansion assessment in the elderly health evaluation.

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Effects of a Standardized Local Thermal-Herbal Intervention on Heart Rate and Perceptual Recovery Following High-Intensity Exercise in Young Adults

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ABSTRACT

Potisan T, Khumprommarach S, Potisaen J. Effects of a Standardized Local Thermal-Herbal Intervention on Heart Rate and Perceptual Recovery Following High-Intensity Exercise in Young Adults. The purpose of this study was to examine the effects of a standardized local thermal-herbal intervention on physiological and perceptual recovery following high-intensity exercise in young adults. Forty healthy male undergraduate students aged 19 to 22 years were randomly assigned to an Experimental Group (n = 20) that received a 10-min bamboo-bed thermal-herbal intervention or a Control Group (n = 20) that received 10 min of passive rest with standardized static stretching. Heart rate (HR), thigh circumference, and rating of perceived exertion (RPE) were measured at baseline, immediately post-exercise, and after recovery. The data were analyzed using a 2 × 3 mixed-design ANOVA. At post-recovery, HR was lower in the Experimental Group than in the Control Group (88.65 ± 4.93 vs. 111.20 ± 4.88 beats·min^{-1}, respectively; $P<0.001$). RPE was also lower in the Experimental Group than in the Control Group (8.55 ± 0.60 vs. 10.75 ± 0.60, respectively; $P<0.001$). No significant group × time interaction was observed for thigh circumference ($P = 0.601$). These findings indicate that a short, monitored local thermal-herbal intervention may support early heart rate and perceptual recovery following high-intensity exercise, which may have practical relevance for post-exercise recovery in exercise physiology settings.

Key Words: Heart Rate, Heat Exposure, Recovery, RPE

INTRODUCTION

Recovery following high-intensity exercise is a central concern in Exercise Physiology because strenuous exercise produces acute cardiovascular, metabolic, neuromuscular, and perceptual stress. Recovery may be considered as either acute or long-term. Acute recovery refers to the restoration that occurs within minutes to hours after a single exercise bout, whereas long-term recovery involves delayed repair and adaptation across days, weeks, or training cycles (9,26). The present study focuses on acute post-exercise recovery following high-intensity exercise. During this early period, heart rate remains elevated as the body attempts to restore cardiovascular homeostasis and regulate circulation. Therefore, heart rate recovery is commonly used as a practical physiological indicator of cardiovascular recovery after exercise (4,19). In addition, the rating of perceived exertion (RPE) provides useful information regarding subjective recovery status and readiness for subsequent activity (5,25).

A variety of post-exercise recovery strategies have been used in athletic and exercise settings, including passive rest, stretching, cold-water immersion, massage, and heat-based modalities (9,26). Cold-based recovery strategies have been widely investigated, particularly for reducing soreness and perceived fatigue. However, heat exposure may also contribute to recovery through increased local blood flow, peripheral vasodilation, reduced muscle stiffness, and enhanced relaxation (2,10). Previous studies on heat-based recovery have commonly focused on sauna bathing, hot-water immersion, or general clinical heat applications (1,6). Although these approaches provide useful evidence, they do not fully explain whether a brief, localized, and culturally derived thermal intervention can influence early physiological and perceptual recovery after high-intensity exercise.

Traditional bamboo-bed thermal-herbal practices are used in some community settings to promote relaxation and physical recovery. However, these practices have rarely been evaluated under standardized experimental conditions using measurable exercise physiology outcomes. In particular, limited evidence is available regarding the effects of a short, monitored bamboo-bed thermal-herbal intervention on heart rate recovery, perceived exertion, and acute thigh circumference responses following strenuous exercise. This gap is important because low-cost and locally available recovery methods may have practical value if they can be standardized, monitored for safety, and evaluated using objective and subjective recovery indicators.

The present study was designed to address this gap by examining the effects of a standardized local thermal-herbal intervention on physiological and perceptual recovery following high-intensity exercise in healthy young adults. The intervention was delivered for 10 min using a controlled bamboo-bed thermal-herbal protocol, while the control condition consisted of passive rest with standardized static stretching. Heart rate and RPE were selected to represent cardiovascular and perceptual recovery, respectively. Thigh circumference was included as a practical, non-invasive indicator of acute lower-limb size change following strenuous exercise, which may reflect transient fluid shifts or muscle swelling (11,12). These variables were assessed before exercise, immediately after exercise, and after the recovery period. It was hypothesized that the bamboo-bed thermal-herbal intervention would result in greater reductions in heart rate and RPE during early recovery compared with the control condition, while producing no significant differential effect on short-term thigh circumference responses.

METHODS

Subjects

Forty (n = 40) healthy male undergraduate students volunteered to participate in this study. The subjects were 19 to 22 years of age and were recruited from Rajabhat Maha Sarakham University, Maha Sarakham, Thailand. All the subjects were physically active and regularly participated in structured physical activity as part of their academic curriculum. The inclusion criteria were normal body mass index and no history of musculoskeletal injury, cardiovascular disease, neurological disorder, or heat-related illness during the previous 6 months.

Prior to participation, all subjects were informed of the study procedures, potential risks, and expected benefits. Written informed consent was obtained from each subject. The study was approved by the Human Research Ethics Committee of Nakhon Ratchasima Rajabhat University, Thailand (Approval No. HE-RDI-NRRU.157/2568), and it was conducted in accordance with the Declaration of Helsinki.

The subjects were matched according to baseline heart rate and body mass index before being randomly assigned to either the Experimental Group (n = 20) or the Control Group (n = 20). The Experimental Group received a standardized bamboo-bed thermal-herbal intervention after high-intensity exercise, while the Control Group received passive rest with standardized static stretching. Random allocation was performed using a computer-generated randomization sequence by a researcher who was not involved in subject recruitment or outcome assessment. Group assignments were concealed in sealed opaque envelopes until baseline measurements had been completed.

An *a priori* power analysis was conducted using G*Power software, version 3.1.9.7. The calculation was based on a mixed-design analysis of variance with 2 Groups and 3 repeated measurements. Assuming a medium effect size of f = 0.25, an alpha level of 0.05, statistical power of 0.80, a correlation among repeated measures of 0.50, and a nonsphericity correction of 1.0, the estimated minimum total sample size was 28 subjects. Therefore, the final sample of 40 subjects was considered adequate for detecting Group × Time interaction effects.

Procedures

All testing was conducted at the Gymnasium of the Sports Hall, Rajabhat Maha Sarakham University, under controlled environmental conditions. Room temperature was maintained at approximately 24°C to 25°C. All subjects were familiarized with the testing procedures before data collection. The dependent variables measured in this study were resting heart rate, thigh circumference, rating of perceived exertion, and recovery attitude scores. Recovery attitude scores were not mentioned in the Introduction.

Measurements were obtained at 3 time points: baseline before exercise (T0), immediately after high-intensity exercise (T1), and immediately after the 10-min recovery intervention (T2). Heart rate was measured using a Polar H10 chest-strap heart rate monitor. Heart rate values were recorded from the stabilized reading during the final 10 sec of each measurement period. During the recovery phase, the subjects maintained a standardized supine resting posture, minimized movement, breathed normally, and refrained from conversation to reduce external influences on cardiovascular recovery.

Thigh circumference was used as a practical indicator of acute exercise-induced muscle swelling. Measurements were obtained on the dominant leg with the subject standing upright in a relaxed position. A non-elastic measuring tape was positioned perpendicular to the longitudinal axis of the femur. Two anatomical sites were measured: the midpoint between the anterior superior iliac spine and the superior pole of the patella, and 5 cm proximal to the superior pole of the patella. Both sites were marked with a skin-safe marker to ensure consistent measurement across time points. Three measurements were taken at each site, and the mean value was calculated. The final thigh circumference value used for analysis was the average of the 2 site-specific means.

Rating of perceived exertion was assessed using the Borg 6 to 20 scale. The subjects reported their perceived exertion at T0, T1, and T2, with higher scores indicating greater perceived effort and fatigue.

To induce acute physiological and perceptual fatigue, the subjects completed a standardized high-intensity circuit exercise protocol. The protocol consisted of 3 consecutive circuits that included 20-m shuttle runs, alternating leg lunges, plank with alternating shoulder taps, push-ups, burpees, and stair running. Brief rest intervals of 15 to 20 sec were provided between exercises according to the demands of each station. All sessions were supervised by trained investigators to ensure proper technique and similar exercise intensity across subjects.

Immediately after the exercise protocol, the subjects completed the assigned 10-min recovery condition. The Experimental Group received a standardized bamboo-bed thermal-herbal intervention. The intervention involved placing both lower limbs on a bamboo bed layered with Thai medicinal herbs, including Blumea balsamifera and Croton oblongifolius Roxb. The herbal layer was covered with a thin cotton cloth to prevent direct skin contact and to maintain hygiene. A controlled charcoal heat source was positioned beneath the bamboo bed, and the surface temperature was maintained at 38°C to 40°C. Temperature was monitored with an infrared thermometer at the proximal thigh, calf, and ankle approximately every 1 to 2 min. Subjects were instructed to report any discomfort, excessive heat sensation, dizziness, or skin irritation. No adverse thermal responses were recorded.

The Control Group completed 10 min of passive rest in a seated position combined with standardized static stretching. The stretching routine targeted the quadriceps, hamstrings, and gastrocnemius muscles. Each stretch was held for 30 sec and repeated twice for each muscle group bilaterally. The subjects were instructed to stretch to the point of mild discomfort without pain and to maintain normal breathing throughout the recovery period.

After the recovery period, the subjects' attitudes toward the assigned recovery protocol were assessed using a researcher-developed recovery attitude scale. The scale consisted of 10 items rated on a 5-point Likert scale and evaluated perceived appropriateness, perceived recovery effectiveness, thermal comfort and safety, environmental suitability, duration adequacy, perceived benefit of the herbal components, and overall satisfaction. Total scores ranged from 10 to 50, with higher scores indicating more favorable attitudes toward the recovery protocol. Content validity was evaluated by 3 experts, and all items achieved an item-objective congruence index of 1.00. Internal consistency reliability in the present sample was acceptable, with Cronbach's alpha values of 0.80 in the Experimental Group and 0.81 in the Control Group.

Statistical Analyses

All statistical analyses were performed using SPSS version 26.0. The data are presented as mean ± standard deviation. The Shapiro-Wilk Test was used to examine the normality of the data, and Levene's Test was used to assess homogeneity of variance. The dependent variables included heart rate, thigh circumference, rating of perceived exertion, and recovery attitude scores.

A 2 × 3 mixed-design analysis of variance was used to examine the effects of Group and Time on heart rate, thigh circumference, and rating of perceived exertion. Group, consisting of experimental and control conditions, was treated as the between-subjects factor. Time, consisting of baseline, immediately post-exercise, and post-recovery measurements, was treated as the within-subjects factor. The Group × Time interaction was the primary effect of interest. The Mauchly's Test was used to assess the assumption of sphericity. When sphericity was violated, the Greenhouse-Geisser correction was applied. When significant main effects or interaction effects were observed, Bonferroni-adjusted pairwise comparisons were used to identify specific differences between groups and across time points.

Partial eta squared was used as the effect size for analysis of variance results. The magnitude of partial eta squared was interpreted as small at 0.01, moderate at 0.06, and large at 0.14. Recovery attitude scores were compared between the Groups using an independent-samples *t*-test when the assumption of normality was met. Cohen's d was calculated to determine the magnitude of between-group differences for recovery attitude scores. Statistical significance was set at $P<0.05$.

RESULTS

All 40 subjects completed the study protocol and were included in the final analysis. No subject withdrew from the study, and no adverse thermal responses were reported during the experimental or control recovery conditions. Baseline characteristics of the subjects are presented in Table 1. There were no significant differences between the Experimental and Control Groups for age, height, body weight, or body mass index ($P > 0.05$). Thus, the 2 Groups were comparable before the intervention.

Immediately after the high-intensity exercise protocol, heart rate and RPE were not significantly different between the 2 Groups. Heart rate was 159.95 ± 3.59 beats·min^{-1} in the Experimental Group and 160.50 ± 5.03 beats·min^{-1} in the Control Group ($P = 0.652$). RPE was 17.27 ± 1.06 in the Experimental Group and 17.83 ± 0.71 in the Control Group ($P = 0.075$). These findings indicate that the exercise protocol produced comparable physiological and perceptual fatigue before the recovery intervention.

Heart Rate

Heart rate responses across baseline, post-exercise, and post-recovery are presented in Table 2. There was a significant main effect of Time for heart rate, $F(2,76) = 3830.82$, $P < 0.001$, $\eta p^2 = 0.990$. There was no significant main effect of Group, $F(1,38) = 1.25$, $P = 0.270$, $\eta p^2 = 0.032$. However, there was a significant Group × Time interaction, $F(2,76) = 75.91$, $P<0.001$, $\eta p^2 = 0.615$. Heart rate was similar between the 2 Groups at baseline and immediately post-exercise. After the recovery period, heart rate was significantly lower in the Experimental Group than in the Control Group (88.65 ± 4.93 vs. 111.20 ± 4.88 beats·min^{-1}, respectively; $P<0.001$).

Thigh Circumference

Thigh circumference responses are presented in Table 2. There was a significant main effect of Time, F(2,76) = 15.42, P < 0.001, ηp^2 = 0.289, indicating that thigh circumference changed across the measurement points. There was no significant main effect of Group, F(1,38) = 0.72, P = 0.391, ηp^2 = 0.019. The Group × Time interaction was not significant, F(2,76) = 0.51, P = 0.601, ηp^2 = 0.013. These findings indicate that the bamboo-bed thermal-herbal intervention did not produce a differential effect on short-term thigh circumference responses compared with the control condition.

Rating of Perceived Exertion (RPE)

RPE responses are presented in Table 2. There was a significant main effect of Time for RPE, F(2,76) = 2354.41, P < 0.001, ηp^2 = 0.984. There was no significant main effect of Group, F(1,38) = 1.05, P = 0.312, ηp^2 = 0.027. However, there was a significant Group × Time interaction, F(2,76) = 13.10, P < 0.001, ηp^2 = 0.216. RPE was similar between the groups at baseline and immediately post-exercise. After the recovery period, RPE was significantly lower in the Experimental Group than in the Control Group (8.55 ± 0.60 vs. 10.75 ± 0.60, respectively; P < 0.001).

Recovery Attitude Scores

Recovery attitude scores were significantly higher in the Experimental Group than in the Control Group (41.15 ± 4.92 vs. 37.70 ± 4.66, respectively; t(38) = .93, P = 0.009). The effect size was moderate (Cohen's d = 0.72). When expressed as mean item scores, the Experimental Group reported higher scores than the Control Group (4.12 ± 0.49 vs. 3.77 ± 0.47, respectively). These findings indicate that subjects in the Experimental Group reported more favorable attitudes toward the assigned recovery protocol.

Table 1. Baseline Characteristics of the Subjects.

Variable	Experimental Group (N = 20)	Control Group (N = 20)	t	P
Age (yrs)	19.75 ± 1.15	20.25 ± 1.07	-1.486	0.154
Height (cm)	171.40 ± 3.94	171.15 ± 5.70	0.158	0.876
Body Weight (kg)	65.85 ± 6.14	63.60 ± 6.80	1.141	0.268
BMI (kg·m^{-2})	21.68 ± 1.70	22.39 ± 1.59	-1.614	0.123

Values are mean ± SD. **BMI** = Body Mass Index.

Table 2. Heart Rate, Thigh Circumference, and RPE Responses Across Time.

Variable	Time Point	Experimental Group (N = 20)	Control Group (N = 20)	P
Heart Rate (beats·min^{-1})	Baseline	71.00 ± 4.10	71.20 ± 5.87	0.912
	Post-exercise	159.95 ± 3.59	160.50 ± 5.03	0.652
	Post-recovery	88.65 ± 4.93	111.20 ± 4.88	<0.001
Thigh Circumference (cm)	Baseline	47.66 ± 2.41	47.04 ± 2.91	0.442
	Post-exercise	48.48 ± 2.43	47.67 ± 3.09	0.343
	Post-recovery	48.05 ± 3.00	47.43 ± 3.05	0.444

RPE (6–20 scale)	Baseline	6.15 ± 0.30	6.15 ± 0.30	1.000
	Post-exercise	17.27 ± 1.06	17.83 ± 0.71	0.075
	Post-recovery	8.55 ± 0.60	10.75 ± 0.60	<0.001

Values are mean ± SD. **RPE** = Rating of Perceived Exertion.

Table 3. Mixed-Design ANOVA Results.

Variable	Effect	df	F	P	ηp²
Heart Rate	Time	2,76	3830.82	<0.001	0.990
	Group	1,38	1.25	0.270	0.032
	Group × Time	2,76	75.91	<0.001	0.615
Thigh Circumference	Time	2,76	15.42	<0.001	0.289
	Group	1,38	0.72	0.391	0.019
	Group × Time	2,76	0.51	0.601	0.013
RPE	Time	2,76	2354.41	<0.001	0.984
	Group	1,38	1.05	0.312	0.027
	Group × Time	2,76	13.10	<0.001	0.216

ηp² = partial eta squared; **RPE** = Rating of Perceived Exertion.

Table 4. Recovery Attitude Scores.

Group	Cronbach's α	Total Score	Mean Item Score	t	P
Experimental	0.80	41.15 ± 4.92	4.12 ± 0.49	2.93	0.009
Control	0.81	37.70 ± 4.66	3.77 ± 0.47		

Values are mean ± SD.

DISCUSSION

Cardiovascular Recovery

The primary finding of the present study was that the standardized local thermal-herbal intervention produced a greater reduction in heart rate during the early recovery period following high-intensity exercise. Heart rate values were comparable between the 2 Groups at baseline and immediately post-exercise, which indicates that the exercise protocol imposed a similar cardiovascular load before the recovery intervention. However, after the 10-min recovery period, the Experimental Group demonstrated a significantly lower heart rate than the Control Group. This finding suggests that the intervention may have facilitated early heart rate recovery following strenuous exercise.

Heart rate recovery is widely recognized as an accessible marker of post-exercise cardiovascular regulation, and it is commonly interpreted as reflecting the balance between sympathetic withdrawal and parasympathetic reactivation during early recovery (13,19). However, because direct autonomic measures such as heart rate variability were not assessed in the present study, the observed reduction in heart rate should be interpreted as improved recovery kinetics rather than definitive evidence of autonomic modulation. This distinction is important because heart rate alone provides a useful applied index of recovery but cannot fully explain the underlying physiological mechanisms.

The greater decrease in heart rate in the Experimental Group may be partly explained by the combined influence of standardized supine recovery posture and localized thermal exposure. In the present protocol, the subjects maintained a controlled recovery posture with minimal movement during the intervention. This may have supported venous return and cardiovascular stabilization during the early recovery period. In addition, thermal exposure has been reported to influence cardiovascular regulation through peripheral vasodilation and reductions in vascular resistance, which may have modified circulatory dynamics during post-exercise recovery (20). Thus, the greater reduction in heart rate observed in the Experimental Group should not be attributed to thermal stimulation alone. Rather, it may reflect the combined effects of localized heat exposure, reduced movement, and the standardized supine recovery posture used during the intervention. In contrast, the Control Group recovered in a seated position, which may also have influenced the between-group difference in heart rate recovery.

Recent studies examining post-exercise hot-water immersion and passive heat exposure have reported measurable effects on vascular responses and recovery-related physiological markers compared with exercise alone (23,24). Although the present intervention used localized lower-limb heating rather than whole-body immersion, the significant Group × Time interaction for heart rate suggests that moderate regional thermal stimulation may be sufficient to influence short-term cardiovascular recovery dynamics. This interpretation is also consistent with previous work showing that heat-based recovery modalities, including sauna bathing and hot-water immersion, may affect cardiovascular and recovery-related responses after exercise (1,10,14).

Perceptual Recovery

In addition to the cardiovascular recovery, the intervention was associated with a greater reduction in perceived exertion during the recovery phase. The RPE values were comparable between the Groups immediately after exercise, indicating that both Groups experienced a similar level of perceived strain before the recovery intervention. After the recovery period, however, the Experimental Group reported significantly lower RPE than the Control Group.

Perceived exertion is influenced not only by cardiovascular strain but also by afferent feedback from working muscles, respiratory effort, thermal sensation, discomfort, and central integration of physiological stress signals (15,25). Therefore, the greater reduction in RPE observed in the Experimental Group may reflect both physiological and perceptual responses to the local thermal-herbal intervention. Local warmth may have contributed to relaxation, reduced perceived discomfort, and the improvement in subjective recovery experience. Heat exposure has also been reported to modify vascular and perceptual responses following exercise, which may partly explain the lower perceived exertion after the intervention (23).

The parallel reductions in heart rate and RPE suggest a coordinated physiological-perceptual recovery response. Previous research has indicated that cardiovascular recovery kinetics, autonomic regulation, and perceived effort responses may be interrelated during post-exercise recovery (16,17). Although the present study did not assess direct autonomic markers, the simultaneous improvements in an objective cardiovascular variable and a subjective perceptual variable indicate that the intervention may have influenced recovery across more than one domain. This is relevant in exercise physiology because both physiological stabilization and perceived readiness are important when determining recovery status and subsequent exercise tolerance.

However, the perceptual findings should be interpreted cautiously. The subjects were not blinded to the recovery condition, and the warmth, novelty, and cultural familiarity of the bamboo-bed thermal-herbal intervention may have influenced perceived comfort and recovery attitudes. Therefore, future studies should include sham-heat or matched non-heated comparison conditions to determine whether the reduction in RPE is primarily attributable to thermal stimulation, expectation, relaxation, or the combined intervention.

Peripheral Responses and Practical Interpretation

In contrast to heart rate and RPE, the intervention did not produce a significant Group × Time interaction for thigh circumference. Although thigh circumference changed across time, the pattern of change did not differ significantly between the Groups. This finding indicates that the local thermal-herbal intervention did not have a detectable differential effect on short-term peripheral swelling within the 10-min recovery window.

This result is physiologically reasonable. Acute increases in muscle girth after strenuous exercise may reflect transient intramuscular fluid shifts, muscle pump effects, and localized edema that may persist beyond the immediate recovery period (11,12). Therefore, a 10-min recovery period may not have been sufficient to detect meaningful differences in thigh circumference between the Groups. In addition, while the circumference measurement is practical and non-invasive, it may be less sensitive than ultrasound, imaging-based muscle thickness assessment, bioimpedance, or biochemical markers for detecting short-term changes in muscle fluid distribution (18,27).

The absence of a significant thigh circumference effect helps clarify the interpretation of the main findings. The observed improvements in heart rate and RPE should not be interpreted as evidence that the intervention reduced acute muscle swelling. Rather, the results suggest that the intervention was more strongly associated with early cardiovascular and perceptual recovery than with immediate changes in peripheral limb size. This distinction is important for avoiding overstatement of the physiological effects of the intervention.

The significantly higher recovery attitude scores in the Experimental Group indicate that the bamboo-bed thermal-herbal intervention was perceived as more acceptable and favorable than the control recovery condition. Although this outcome does not provide direct physiological evidence of recovery, it is useful as a supportive measure because perceived comfort, safety, and acceptability may influence the practical use of recovery strategies in applied exercise settings.

Exercise Physiology Implications and Future Research

The present findings have practical implications for exercise physiology because early cardiovascular stabilization following strenuous activity is important for safe workload progression and recovery management. Delayed heart rate recovery has been associated with sustained post-exercise physiological strain, and recovery strategies that facilitate more rapid cardiovascular normalization may support more controlled exercise dosing in supervised settings (21,22). In the present study, the local thermal-herbal intervention was associated with a steeper decline in heart rate and a greater reduction in perceived exertion within a short recovery period that suggest potential practical value as a monitored post-exercise recovery strategy.

The integrated reduction in heart rate and RPE may also be relevant in contexts where physiological stabilization and perceived readiness are both important for subsequent activity. Studies in exercise rehabilitation and clinical exercise settings have emphasized the importance of perceived effort and cardiovascular responses for safe exercise progression and return to activity (3,7,8). Although the present study was conducted in healthy young adults rather than clinical populations, the findings provide preliminary evidence that controlled local thermal exposure may influence early recovery responses in a measurable way.

Limitations in this Study

Several limitations should be acknowledged. First, the sample consisted only of healthy young male undergraduate students, which limits generalizability to females, older adults, trained athletes, sedentary individuals, or clinical populations. Second, the recovery period was limited to 10 min, so the findings describe only early recovery and not delayed recovery, subsequent performance, or 24- to 48-hr responses. Third, direct measures of autonomic regulation, metabolic responses, peripheral blood flow, skin temperature, core temperature, or muscle oxygenation were not included. Therefore, mechanistic interpretations remain indirect. A methodological limitation is that recovery posture was not fully matched between groups. The Experimental Group recovered in a standardized supine position during the bamboo-bed thermal-herbal intervention, whereas the Control Group recovered in a seated position during passive rest and stretching. Because body position may influence venous return, peripheral blood flow, and heart rate recovery, the heart rate findings should be interpreted as reflecting the combined influence of the intervention condition and recovery posture.

The control condition also warrants consideration. Passive rest with static stretching was selected as a pragmatic field-based comparison condition, but stretching may produce minor physiological or perceptual effects. Future research should include passive-rest-only, sham-heat, non-herbal heat, and herbal-without-heat comparison conditions to isolate the specific effects of thermal stimulation, herbal components, posture, and expectation. Longer monitoring periods and performance-based outcomes would also help determine whether early reductions in heart rate and RPE translate into improved subsequent exercise capacity or functional recovery.

CONCLUSIONS

The present study showed that a 10-min standardized local thermal-herbal intervention resulted in significantly lower heart rate and rating of perceived exertion during early recovery following high-intensity exercise compared with passive rest and standardized static stretching. In contrast, the intervention did not produce a significant differential effect on short-term thigh circumference responses. Also, the subjects in the Experimental Group reported more favorable recovery attitude scores, which suggest that the intervention was well accepted under supervised and temperature-controlled conditions.

These findings contribute to exercise physiology by demonstrating that a brief, monitored local heat-based recovery intervention may influence early cardiovascular and perceptual recovery after strenuous exercise. The results suggest that localized thermal exposure may be a practical recovery strategy for supporting short-term post-exercise recovery when applied with appropriate temperature control and supervision. However, because direct autonomic, vascular, metabolic, and performance-related measures were not assessed, the findings should be interpreted as preliminary evidence of improved early heart rate and perceptual recovery rather than definitive evidence of a specific physiological mechanism. Future studies incorporating heart rate variability, vascular measures, metabolic biomarkers, sham-control designs, and longer recovery periods are warranted to clarify the mechanisms and applied significance of this recovery approach.

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The Influence of Resistance Training on Muscle and Bone Health Among Premenopausal, Perimenopausal, Menopausal, and Postmenopausal Females: An Umbrella Review

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ABSTRACT

Shook A. The Influence of Resistance Training on Muscle and Bone Health Among Premenopausal, Perimenopausal, Menopausal, and Postmenopausal Females: An Umbrella Review. Muscle mass, strength, and bone mineral density losses occur across the female lifespan and contribute to functional decline and fracture risk. Resistance training improves muscular performance, although adaptations in lean mass and skeletal outcomes vary by population and measurement site. This review examines the effects of resistance training on muscle and bone health outcomes in females across the lifespan and aims to inform a specific frequency, intensity, and type of exercise prescription. PubMed and Cochrane Library databases were searched using predefined terms. After screening 436 records, five meta-analyses of resistance training in females aged 12 years and older met the inclusion criteria. Resistance training consistently improved muscular strength across the meta-analyses. Changes in muscle mass were heterogeneous, and several meta-analyses reported minimal or no change in lean mass. Bone mineral density responses were site specific, with more favorable outcomes at the lumbar spine than at the hip or femoral neck. Resistance training is supported as an effective intervention for strength development in females. Effects on muscle mass and bone mineral density vary across populations and measurement sites, indicating that exercise prescriptions should prioritize strength and functional outcomes while recognizing variability in muscle hypertrophy and bone mineral density.

Key Words: Bone Health, Resistance Training, Muscle Health, Women’s Health

INTRODUCTION

The included meta-analyses (MAs) were mapped to various female life phases. Reviews of adolescent and young adult females were classified as premenopausal, studies including middle-aged cohorts without menopause were considered mixed adult populations, and reviews focused on older adult women were interpreted as postmenopausal samples. No meta-analysis specifically isolated perimenopausal participants, therefore, the conclusions regarding this stage are interpreted cautiously. Lean mass refers to all non-fat tissue including skeletal muscle, bone, organs, and body water. Fat-free mass (FFM) represents all body mass excluding adipose tissue and, therefore, includes skeletal muscle, bone mineral content, and body water. Muscle mass (MM) refers specifically to skeletal muscle tissue. In this umbrella review, although these outcomes were interpreted as related. Some of the included MAs reported lean mass or FFM rather than direct skeletal muscle measures.

MM decreases approximately 3 to 8% per decade after the age of 30 and this rate of decline is even higher after the age of 60 (12). Longitudinal studies show that in people aged 75 years and older, MM is lost at a rate of 0.64 to 0.70% per year in women (16). Strength loss among women occurs much more rapidly. Longitudinal studies show that at age 75 years, strength is lost at a rate of 2.5 to 3% per year in women (16). Studies that evaluated changes in mass and strength in the same sample reported a loss of strength 2 to 5 times faster than loss of mass (16). Bone mineral density (BMD) loss among women had a greater decline with age compared to males (2). MM, muscle strength, and BMD play a fundamental role in health and quality of life. Especially with age, older adults' ability to perform daily activities begin to decline. These age-related losses women experience have adverse health related consequences, such as sarcopenia and osteoporosis. Sarcopenia is the age-related progressive loss of MM and strength and the main symptom of the condition is muscle weakness (7). Sarcopenia is a type of muscle atrophy primarily caused by the natural aging process (7). Osteoporosis is a disease that weakens bones causing them to become thinner and less dense (6). People with osteoporosis are much more likely to experience broken bones (6). This age-related decrease may be a result of poor lifestyle choices and menopausal related outcomes including decreased estrogen.

The decrease in quality of life due to disability and independence is associated with significant healthcare costs with an ever-aging population in the United States. Postmenopausal women with reduced MM have a 2.1 times higher risk of falling and a 2.7 times greater risk of sustaining a fracture compared to women with preserved MM (18). The prevalence of sarcopenia is higher in females than in males (13). Females are also more susceptible than males to osteoporosis (21). Osteoporosis and sarcopenia are common in older age and associated with significant morbidity and mortality (9). The estimated cost of hospitalizations in individuals with sarcopenia is $40.4 billion (10). Osteoporosis is responsible for 2 million broken bones and $19 billion in related costs every year (19). These outcomes of sarcopenia and osteoporosis can burden one's quality of life due to disability and reduction in independence, which are associated with significant healthcare costs in the United States.

The practice of exercise, more specifically resistance training (RT), is widely recommended for postmenopausal and older females because it is a safe and well-accepted nonpharmacological strategy to mitigate the negative impacts of menopause and aging on MM (17). This type of training could reduce the influence of sarcopenia to a greater extent, prevent the loss of muscle functionality, and reverse the deterioration of the structure due to the aging of the person. These changes would result in a higher quality of life for postmenopausal women (17). Also, the increase in the mechanical load in RT could increase BMD, with a corresponding reduction in the incidence of osteopenia, osteoporosis, and osteoporotic fractures (17). This review seeks to answer the question of RT on improving muscle and bone health outcomes of females across the lifespan with the intent to determine a recommended exercise prescription since there currently is a gap in the literature.

Resistance training provides broad physiological benefits beyond improvements in muscular strength and body composition (Table 1). These include improvements in metabolic health, vascular function, sleep, and prevention of chronic diseases that include diabetes and cardiovascular diseases. These systemic benefits reinforce RT as a foundational intervention across the female lifespan.

METHODS

This study was conducted as an umbrella review of the findings from published meta-analyses (MAs) of randomized controlled trials. The MAs were compared at the outcome level rather than pooling the individual participant data. Overlapping primary trials across reviews were examined by cross-referencing study lists. When discordant findings occurred, the conclusions were based on direction of effect, magnitude of pooled effect estimates, consistency across the reviews, and clarity of statistical reporting. A structured methodological appraisal of the included MAs was performed that focused on search transparency, inclusion criteria clarity, risk of bias assessment, heterogeneity reporting, and appropriateness of the statistical synthesis. Most of the reviews demonstrated clear eligibility criteria and appropriate statistical analysis. However, variability did exist in the reporting of the heterogeneity metrics and the risk-of-bias assessment. These differences were considered when interpreting the strength and certainty of the evidence. Although this appraisal was informed by key AMSTAR 2 domains, a formal AMSTAR 2 scoring process was not applied.

With assistance of a medical librarian for this review, the databases searched were PubMed and Cochrane that yielded 436 articles. After removing 4 duplicates and excluding 427 articles for wrong outcomes, inclusion of both RT and aerobic training in the same intervention, inclusion of men, inclusion of females with cancer, incorrect study design, and foreign language, 5 eligible articles remained. This review synthesizes published MAs; overlapping primary trials were considered when interpreting findings, and discordant results were resolved by prioritizing consistency across the reviews and higher methodological quality. Overlap of primary trials across MAs was examined by comparing the included study lists, and the discordant findings were interpreted based on consistency across the reviews and methodological rigor.

The **inclusion criteria** for this search were systematic reviews and MAs of randomized control trials that included a RT program, weight lifting, power lifting, strength training, machines, resistance bands, and or a combination of these compared to various RT modes and volumes and no exercise, report MM improvements, muscle strength improvements, and increased BMD pre- and post-intervention, females 12 years of age and older. With or without having metabolic, renal or cardiovascular diseases or conditions requiring medications for each, such as Prediabetes, Types 2 Diabetes Mellitus, Type 1 Diabetes Mellitus, Hypertension, Obesity, Hypothyroidism, Fatty Liver Disease, Gastro Esophageal Reflux Disease, Chronic Obstructive Pulmonary Disorder, Asthma, and Depression, and published and peer reviewed in English until 11/9/2024. Premenopause is when there are no symptoms of perimenopause or menopause even though some hormonal changes may have occurred, but periods still occur and a woman is considered to be in the reproductive years (5). Perimenopause is when there are symptoms of menopause, such as irregular period cycle, hot flashes, sleep disturbances, and mood swings (5). Menopause occurs when the ovaries produce so little estrogen that the eggs are no longer released, which causes a stop to periods (5). Postmenopause is considered after menopause or the years of a woman's life after menopause occurs (3). The **exclusion criteria** were men, females less than 12 years old who show no signs of missed period, and any exercise group that consisted of both aerobic and RT.

Table 1: Benefits of Resistance Training (1,4,8).

↑	**Basal metabolic rate**
↑	**Mental health**
↑	**Cardiorespiratory health**
↑	**Vascular health**
↑	**Muscle and muscle oxidative capacity**
↑	**Strength and power**
↑	**Improves sleep**
↑	**Bone density**
↑	**Prevention or control of chronic conditions such as diabetes, heart diseases, arthritis, and obesity**
↑	**Remaining independent with age**
↑	**Prevent cognitive decline**
↑	**Weight management through increased muscle to fat ratio**
↑	**Self-confidence and self esteem**
↑	**Insulin sensitivity**
↑	**Posture**
↓	**Mortality independent of aerobic exercise**
↓	**Risk from injury**

Table 2: FIT Exercise Prescription.

Frequency	Intensity	Type
2 to 5 d/wk	40 to 90% 1RM or 5 to 30 repetitions (most often 8 to 15 repetitions) and 1 to 3 sets (most often 3 sets)	RT including LVRT and HVRT (Machines, cables, elastic bands, free weights, and RT in water)

***Abbreviations: RT**, Resistance Training; **LVRT**, Low Volume Resistance Training; **HVRT**, High Volume Resistance Training; **d**, Day; **wk**, Week; **1RM**, One Repetition Maximum; **FIT**, Frequency, Intensity, Time.

RESULTS

RT consistently improved muscular strength across the analyses. The outcome data are presented in Table 3.

Table 3: Strength, Muscle Mass, and Bone Mineral Density Outcomes.

Authors and Year	Population	Intervention	Duration	Results
		Strength		
Kelley and Kelley 2004 (14)	Premenopausal women	Lower-body RT	18 to 52 weeks	Significant improvement in muscular strength (P < 0.001). No significant changes observed in BMD or lean mass.
González-Gálvez et al. 2024 (11)	Postmenopausal women	RT compared with stretching or sedentary lifestyle	12 to 56 weeks	Significant improvements in upper and lower limb strength (P < 0.001). No statistically significant pooled effect for BMD (P = 0.29).

Authors and Year	Population	Intervention	Duration	Results
		Muscle Mass		
Zeng and Peng 2020 (20)	Premenopausal and postmenopausal females	Various forms of RT	8 to 60 weeks	Heterogeneous findings. Significant increases in FFM in several subgroups. Skeletal muscle mass changes were not statistically significant and confidence intervals crossed the null value.
Nunes et al. 2024 (17)	Postmenopausal women	Low-volume vs. high-volume RT	8 to 22 weeks	Small pooled hypertrophy estimates. High-volume RT ~1.3 kg ($P = 0.53$)
Authors and Year	**Population**	**Intervention**	**Duration**	**Results**
		Bone Mineral Density		
Martyn-St James and Carroll 2006 (15)	Premenopausal women	Progressive RT	20 to 72 weeks	Significant improvements in lumbar spine BMD ($P < 0.00001$)

***Abbreviations:** **RT**, Resistance Training; **BMD**, Bone Mineral Density; **kg**, Kilogram; **FFM**, Fat-Free Mass.

DISCUSSION

The present umbrella review synthesized findings from 5 MAs evaluating the influence of RT on MM, muscular strength, and BMD in females across the lifespan. The most consistent and reproducible adaptation observed across all the included reviews was improvement in muscular strength. Strength gains were reported regardless of life stage, intervention duration, or resistance modality, indicating that neuromuscular adaptations represent the most reliable physiological response to resistance training in the female populations. These physiological adaptations are likely taking place rather than just structural hypertrophy alone, which may explain their consistency across premenopausal and postmenopausal females.

In contrast, adaptations in muscle mass were heterogeneous. Several MAs reported small to moderate increases in lean mass or FFM; whereas, others reported no statistically significant changes. The variability likely reflects differences in baseline training status, supervision, total training volume, and measurement methodology. Studies involving previously untrained individuals demonstrated more pronounced increases in lean mass compared with those that included trained participants. These observations suggest that lean mass change should not be interpreted as the primary marker of intervention success when evaluating resistance training efficacy in females.

Conflicting findings across the studies are likely explained by differences in intervention duration, training intensity, and participant baseline characteristics. Shorter duration interventions and lower training volumes were less likely to produce measurable hypertrophy; whereas, longer duration and higher intensity protocols demonstrated more favorable outcomes. Additionally, previously untrained individuals demonstrated greater responsiveness when compared with the trained populations. These factors contributed to the variability observed in the MM and the BMD outcomes.

The strength outcomes were consistent. They represented the most robust finding across the MAs, while the MM and the BMD outcomes should be interpreted as conditional and dependent on training parameters and participant characteristics. BMD responses were site-specific. Improvements were more frequently observed at the lumbar spine compared with the femoral neck or total hip. This pattern aligns with biomechanical principles, as spinal loading during multi-joint RT produces localized compressive strain sufficient to stimulate physiological adaptations at the bone. In contrast, interventions lacking adequate strain at the hip may not provide sufficient stimulus for measurable adaptation. Female life-stage across included MAs primarily consisted of premenopausal and postmenopausal samples, with mixed adult cohorts in several reviews. No included MA specifically isolated perimenopausal populations; therefore, the conclusions regarding transitional hormonal stages should be interpreted cautiously. Nonetheless, the consistency of strength outcomes across age groups suggests that resistance training remains beneficial throughout the female lifespan.

From a clinical interpretation perspective, the findings support prioritizing progressive overload and consistent participation over just focusing on hypertrophy of MM. The recommended exercise parameters are summarized in Table 2. Training 2 to 3 days per week at moderate to vigorous intensities appears sufficient to elicit meaningful strength adaptations. Strength improvement may represent the most reliable and clinically meaningful indicator of program effectiveness in female populations.

The exercise prescription outlined in Table 2 is derived directly from the interventions demonstrating the most consistent strength improvements across the included MAs.

Kelley and Kelley (14) and González-Gálvez et al. (11) reported significant strength improvements using moderate to high intensity RT performed 2 to 3 days per week. Similarly, Zeng and Peng (20) and Nunes et al. (17) included protocols utilizing intensities ranging from approximately 40 to 90% of 1 repetition maximum with multiple sets per exercise.

These findings support a frequency of 2 to 5 days per week and moderate to vigorous intensity RT as the most reproducible strategy for improving strength outcomes. Therefore, the FIT parameters reflect evidence-informed ranges derived from the most consistent and statistically robust interventions rather than the full range of protocols reported across studies. The exercise prescription is summarized in Table 2.

STRENGTHS AND LIMITATIONS

This umbrella review synthesizes findings from multiple MAs of randomized controlled trials examining RT in females across the lifespan. It provides a higher-level summary of evidence across diverse populations and training interventions. Strengths of this review include the systematic search strategy, structured comparison of outcome measures across MAs, and clear differences in body composition measures such as lean mass, FFM, and MM. This umbrella review also improves interpretation across different life stages and outcome measures.

Limitations in this Study

Several limitations should be acknowledged. First, the number of eligible MAs was limited, and variation in study design, intervention protocols, and measurement techniques may contribute to heterogeneity in reported outcomes. Second, menopausal status was not consistently stratified across the included reviews, limiting life-stage interpretation specific for perimenopausal populations. Third, methodological appraisal was conducted using a structured qualitative approach informed by AMSTAR 2 domains rather than a formal AMSTAR 2 scoring instrument, which may limit direct comparison of methodological quality across the reviews. Despite these limitations, the consistent direction of strength outcomes across MAs supports the robustness of the primary conclusions.

From a practical perspective, these findings reinforce RT as a cornerstone intervention for maintaining musculoskeletal health in females across the lifespan. While hypertrophy and skeletal adaptations may vary depending on training dose, measurement methodology, and life stage, the consistent strength improvements observed across MAs highlight the reliability of the neuromuscular adaptations to RT. Clinically and within the exercise prescription frameworks, prioritizing progressive overload and long-term adherence may be more important than targeting specific hypertrophy thresholds, particularly in female populations where functional strength outcomes are strongly linked to independence, fall prevention, and quality of life.

CONCLUSION

Resistance training consistently improves muscular strength in females across their lifespan and represents a clinically meaningful intervention for maintaining functional capacity and independence. In contrast, adaptation in MM and BMD is variable and appears dependent on training duration, intensity, the participant characteristics, and the anatomical site of measurement. From a clinical perspective, these findings support prioritizing progressive overload and long-term adherence rather than focusing solely on muscle hypertrophy or structural outcomes. Resistance training should be implemented as a foundational component of prevention and treatment strategies that target age-related decline. Future research should standardize resistance training protocols, improve reporting of menopausal status, and evaluate long-term adaptations to better define dose-response relationships for muscle and bone outcomes.

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Effectiveness of Home-Based Exercise Program Combined with Stretching and Massage to Improve Range of Motion and Reduce Muscle Pain

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Abstract

Toyingpaiboon P, Sriramatr S, Mitranun W, Anek Achariya, Silalertdetkul S. Neck and shoulder muscle pain is a common condition that primarily affects office workers. The purpose of this study was to evaluate the effects of a home-based exercise on muscle pain and range of motion in individuals who have neck pain. Sixty participants were allocated to an Exercise Group (N = 30) and a Control Group (N = 30). Participants aged 25 to 45 years were office workers, reported neck pain and did not engage in regular exercise. The Exercise Group completed 8-week program consisting of upper-body exercise alongside stretching, followed by self-massage. Muscle pain, neck range of motion, and muscle strength were assessed at weeks 0 (baseline), 4, and 8. The data were analyzed using two-way repeated-measures analyses, with a significance level of $P < 0.05$. Neck muscle pain ($P < .001$) and left trapezius muscle pain ($P < .001$) in the Exercise Group were significantly lower than in the Control Group. Neck muscle, left trapezius muscle, right trapezius muscle, and right rhomboid muscle pain were suppressed at weeks 4 and 8 in the Exercise Group (all, $P < .001$). Left and right neck lateral flexion was significantly different between the Control Group and the Exercise Group at weeks 4 and 8 ($P < .05$). However, there were no significant differences between the both Groups in muscle strength. In the Exercise Group, baseline left rhomboid muscle pain was significantly correlated with left lateral flexion ($r = - .40$, $P = .03$), right lateral flexion ($r = - .48$, $P = .01$), left upper trapezius muscle pain ($r = .76$, $P < .001$), and right upper trapezius muscle pain ($r = .76$, $P < .001$). In the Control Group, baseline neck muscle pain was significantly associated with right rhomboid muscle pain ($r = .42$, $P = .02$) and right hand-grip strength ($r = .36$, $P = .049$). These findings suggest that a home-based upper-body exercise program combined with stretching and self-massage effectively improves neck movement and reduces muscle pain.

Key Words: Home-Based Exercise, Muscle Pain, Neck Pain, Range of motion, Self-massage

INTRODUCTION

Neck and shoulder muscle pain is a prevalent condition, particularly among office workers and individuals who are addicted to smartphones (4,18). The main cause of neck and shoulder muscle pain is repetitive muscle contraction for long periods without any change in posture, or sitting with improper posture, especially those whose jobs require sitting in front of a computer for long hours. Neck and shoulder muscle pain is associated with multiple adverse outcomes that included low health-related quality of life, muscle pain, muscle tenderness, muscle tension, and decreased range of motion and muscle strength (13,20,25). Consequently, strategies to prevent neck and shoulder pain are of substantial importance.

Exercise, massage, and stretching have been identified as effective strategies for preventing muscle weakness, reducing pain, and improving the range of motion caused by work-related neck pain (2,3,6,24). Previous studies provide supporting evidence regarding the effectiveness of exercise in addressing neck and shoulder muscle pain (16). Stretching combined with massage reduces neck pain and increases neck range of motion (5). Collectively, these findings suggest that exercise, stretching, and massage may be beneficial for improving muscle pain and range of motion.

The effect of exercise, massage, and stretching on muscle pain and range of motion remains incompletely understood and warrants further investigation, particularly among individuals with neck and shoulder pain. A previous study reported that massage was more effective than exercise in improving range of motion and reducing neck muscle pain (31). Moreover, the exercise and manual therapy inhibit muscle pain greater than usual care in physiotherapy (11). Interestingly, it has been suggested that strengthening combined with stretching is more effective than exercise alone for reducing muscle pain in myofascial pain conditions (22). Accordingly, a multimodal intervention integrating upper-body exercise, stretching, and subsequent massage may be particularly effective in reducing pain and improving range of motion in individuals with neck and shoulder pain.

The exercise behavior, quality of life, substrate oxidation, and gas exchange were adversely affected during the COVID-19 pandemic (9,34). Home-based and online exercise programs have become increasingly popular and may represent viable options for sustained participation, particularly when exercise behaviors are disrupted. Previous studies have shown that online exercise interventions can improve balance, muscle strength, blood pressure, and psychological well-being (7,12,26). Additionally, home-based exercise using a smartphone has been reported to increase range of motion and reduce neck pain (17). Despite growing interest in home-based exercise intervention, the effectiveness of a combined program incorporating home-based exercise, stretching, and subsequent self-massage for reducing pain and improving range of motion, specifically among individuals with neck and shoulder pain, remains insufficiently established and requires further investigation.

Consequently, a home-based exercise program combining exercise and stretching followed by self-massage may represent an effective alternative for reducing muscle pain levels and improving range of motion in individuals with neck and shoulder pain. Moreover, it may also enhance work performance by alleviating discomfort and improving mobility, thereby enabling employees to perform tasks more effectively and comfortably. Consequently, the objective of this research was to investigate the effects of a home-based exercise program incorporating stretching and subsequent self-massage on muscle pain and range of motion among individuals with neck and shoulder pain.

METHODS

Research Design

This study consists of a Control Group and an Exercise Group among individuals with neck muscle pain. The participants in the Exercise Group completed a home-based program consisting of exercise, stretching, and self-massage. The participants in the Control Group were instructed to maintain their usual activities and did not receive any exercise, stretching, or massage intervention. Muscle pain score, range of motion, muscle strength, blood pressure, and heart rate were assessed in the laboratory at weeks 0 (baseline), 4, and 8 in both Groups. This research has been approved by the Human Research Ethics Committee of Srinakharinwirot University (IRB number SWUEC-G119/2566E).

Participants

A total of 60 men and women were recruited and allocated to either a Control Group (N = 30) or an Exercise Group (N = 30). The ***Inclusion criteria*** included aged between 25 and 40 years old, employment in an office-based occupation, with a body mass index (BMI) ranging from 18.5 to 24.9 kg/m², and having a neck muscle pain score at least level six by using the Visual Analogue Scale (VAS). Participants were required to have no history of musculoskeletal or bone-related disorders and no serious pre-existing medical conditions (e.g., cardiovascular disease or cancer). In addition, participants were required to be free of COVID-19 infection at the time of study participation. The ***Exclusion criteria*** included a BMI lower than 18.5 or higher than 24.9 kg/m², and the presence of musculoskeletal or bone-related disorders.

Preliminary Assessment

All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) (21). Neck muscle pain score was assessed using a 0–10 Visual Analogue Scale (VAS), where 0 indicated no pain, and 10 indicated the worst pain imaginable (27). Muscle strength, neck muscle pain score (Visual Analogue Scale), resting blood pressure (mmHg) and heart rate (beats/min) (Omron, Japan) were measured. The neck range of motion was evaluated during the initial assessment using a measuring tape. In addition, demographic and work-related characteristics, including computer type, chair type, sitting duration, computer monitor height, chair height, and sitting position, were collected via questionnaire and compared between the control and exercise groups.

Muscle Strength Assessment

Muscle strength was assessed using a back-leg dynamometer (Takei, Japan) and a hand grip dynamometer (Takei, Japan). The static muscle strength was measured during a specific range of motion where the muscle length remains unchanged. Each test was performed 3 times, and the highest value was recorded for analysis.

Muscle Pain Assessment

Neck muscle pain score was assessed using the Visual Analogue Scale (VAS) as described above. In addition, upper trapezius and rhomboid muscle pain were assessed (Commander Echo™ Wireless Algometer, USA), which measures pain sensitivity by applying pressure to specific tender points on both sides of the body.

Range of Motion Assessment

The neck range of motion (ROM) was evaluated in three directions, including flexion, extension, and lateral flexion, using a measuring tape. The left and right lateral flexion was measured by the distance between the mastoid process and the acromion process of the shoulder. The neck flexion and extension were measured by the distance between the chin and the suprasternal notch of the sternum.

Exercise Group

This home-based exercise intervention consists of 5 minutes of warm-up, 35 minutes of exercise, 12 minutes of self-stretching, followed by 8 minutes of self-massage. Participants completed the program 3 times per week for 8 weeks. At study initiation, researchers provided instruction and demonstrations of all exercise, stretching, and self-massage procedures. Weekly Zoom follow-up sessions were conducted to monitor participation, provide support, and reinforce correct technique and adherence.

The warm-up comprised marching in place, high-kneed walking, brisk walking, and upper-body dynamic stretching, beginning with slow, low-intensity movements. Then, the participants performed moderate-intensity exercises approximately 60 to 70% of their maximum heart rate (MHR) for 35 minutes. The exercise session consisted of bodyweight movements, including wall slide, I-Y-T-W raise, superman, lat pulldown, scapular push-up, inchworm, spider lunges with rotation, and deep squat with thoracic rotation. These exercises were selected to primarily target the upper body.

In the stretching session, the participants performed active static stretching targeting the neck, shoulders, upper back, and trapezius muscles. The protocol included stretches for the neck extensor, upper trapezius, levator scapulae, rhomboid, rotator cuff, shoulder, latissimus dorsi, trunk rotation, and downward-facing dog at the wall. Each stretch was held for a prescribed duration, with a total stretching time of approximately 12 minutes. Subsequently, the participants performed 8 minutes of self-massage, including deep friction and kneading on the neck muscles, upper trapezius muscle, levator scapulae muscle, and rhomboids muscle on both sides of the body.

Statistical Analysis

Data were analyzed using the SPSS software (SPSS version 24, IBM, Illinois, USA). Descriptive statistics were calculated, including the means and standard deviation, were calculated for muscle pain, muscle strength, range of motion, blood pressure, and heart rate. The normality of the distribution of the dependent variables was assessed. A two-way repeated-measures analysis of variance (ANOVA) was performed to examine differences in muscle pain, muscle strength, and range of motion between the exercise and control groups over time. Statistical significance was set at $P < 0.05$. The sample size was estimated using G*Power 3.1.9.4 based on an assumed effect size of 0.7, a significance level (α) of 0.05, and statistical power ($1 - \beta$) of 0.80 (15,29). The analysis indicated that a minimum of 26 participants per group was required. To allow for potential attrition and maintain adequate statistical power, the sample size was increased by 20%, resulting in a final target of 30 participants per group.

RESULTS

Age ($P = .95$), body mass ($P = .09$), height ($P = .23$), body mass index ($P = .18$), heart rate ($P = .25$), systolic blood pressure ($P = .72$), diastolic blood pressure ($P = .50$), and muscle pain score ($P = .51$) did not differ significantly between the Control Group and the Exercise Group. The data are presented in Table 1. Most of the participants reported using a personal computer, working in a chair with a backrest and armrests, continuously sitting for more than 4 hours before taking a break. Their monitor was positioned below eye level, while keeping their feet flat on the floor with their legs dangling. These findings are also summarized in Table 1.

Table 1. The Participants' Characteristics in the Control and Exercise Groups (N = 60). The Data are Presented as Mean ± Standard Deviation and Numbers (percentages).

	Exercise (N = 30)	**Control** (N = 30)
Age (years)	33.2 ± 4. 3	33.3 ± 4.5
Body Mass (kg)	61.8 ± 5.4	64.0 ± 4.4
Height (cm)	166.3 ± 4.5	167.7 ± 4.3
Body Mass Index (kg/m²)	22.3 ± 1.3	22.7 ± 1.3
Heart Rate (beats/min)	74.8 ± 4.6	76.1 ± 4.3
Systolic Blood Pressure (mmHg)	125.6 ± 5.5	125.2 ± 4.4
Diastolic Blood Pressure (mmHg)	74.8 ± 5.7	75.8 ± 5.7
Neck Muscle Pain Score	6.8 ± 0.8	6.7 ± 0.7
Gender		
Men	21 (70)	19 (63)
Women	9 (30)	11 (37)
Computer Type		
Laptop	8 (27)	2 (7)
Personal computer	22 (73)	28 (93)
Chair Type		
With a backrest and without armrests	7 (23)	5 (17)
With a backrest and with armrests	23 (77)	25 (83)
Sitting Duration		
2-4 hours	3 (10)	4 (13)
>4 hours	27 (90)	26 (87)
Computer Monitor Height		
At eye level	6 (20)	7 (23)
Below eye level	24 (80)	23 (77)
Chair Height		
Feet suspended above the ground	3 (10)	2 (7)
Feet flat on the ground	27 (90)	28 (93)
Sitting Position		
Legs dangling	17 (57)	17 (57)
Lotus position	8 (27)	9 (30)
Legs crossed	5 (17)	4 (13)

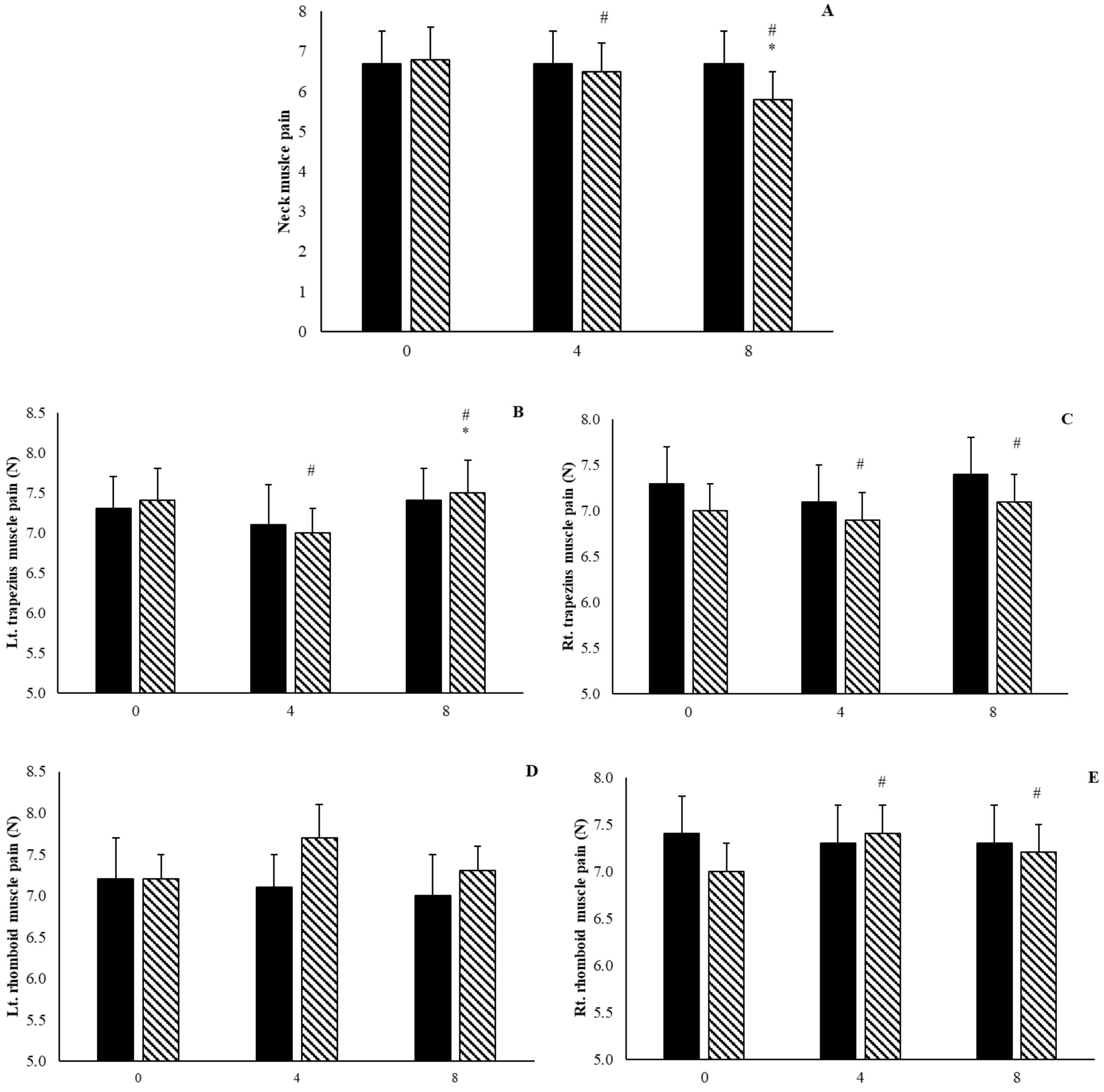

Figure 1. Neck Muscle Pain (A), Left Trapezius Muscle Pain (B), Right Trapezius Muscle Pain (C), Left Rhomboid Muscle Pain (D), Right Rhomboid Muscle Pain (D) on Weeks 0, 4, and 8 in the Control (■) and Exercise (▨) Groups (N = 60). *Statistically Significant Difference Between the Exercise and Control Groups, P < .05. #Statistically Significant Difference Between Baseline (Week 0) and Weeks 4 and 8, P < .05.

The neck muscle pain in the Exercise Group was lower than the Control Group at week 8 (P < .001; time group interaction, P < .001; trial effect, P = .04; time effect, P < .001). The left trapezius muscle pain in Exercise Group was significantly lower than Control Group at week 8 (P < .001; time x trial interaction, P < .001; trial effect, P = .002; time effect, P = .01). No statistically significant between-group differences were observed for the right trapezius muscle (time x trial interaction, P = .01; trial effect, P = .19; time effect, P < .001), the left rhomboid muscle (time x trial interaction, P = .001; trial effect, P = .27; time effect, P = .15), and the right rhomboid muscle pain (time x trial interaction, P = .05; trial effect, P = .36; time effect, P = .003). Within the Exercise Group, neck muscle pain, left trapezius muscle pain, right trapezius muscle pain, and right rhomboid muscle pain decreased at weeks 4 and 8 (all, P < .001). These results are presented in Figure 1.

Table 2. Neck Range of Motion at Weeks 0, 4, and 8 in the Control and Exercise Groups (N = 60). Data are Presented as Mean ± Standard Deviation.

	Week 0		Week 4		Week 8	
	Exercise (N = 30)	Control (N = 30)	Exercise (N = 30)	Control (N = 30)	Exercise (N = 30)	Control (N = 30)
Lt. Lateral Flexion (cm)	13.6 ± 0.5	13.7 ± 0.5	13.4 ± 0.5[#]	13.9 ± 0.5[*]	13.2 ± 0.5[#]	13.8 ± 0.5[*]
Rt. Lateral Flexion (cm)	13.7 ± 0.5	13.6 ± 0.7	13.4 ± 0.5[#]	13.8 ± 0.7[*#]	13.1 ± 0.6[#]	13.7 ± 0.7[*#]
Extension (cm)	19.3 ± 0.6	19.2 ± 0.5[*]	19.4 ± 0.6[#]	19.2 ± 0.5[*]	19.5 ± 0.6[#]	19.3 ± 0.5[*]
Flexion (cm)	12.4 ± 1.0	12.2 ± 1.0	12.1 ± 1.0[#]	12.2 ± 1.0	11.8 ± 1.0[#]	12.3 ± 1.0

[*] Statistically significant difference between the Exercise Group and the Control Group, P < .05.
[#] Statistically significant difference between baseline (week 0) and weeks 4 and 8, P < .05.

There was no statistically significant difference between the Exercise Group and the Control Group for left neck lateral flexion (P = .73), right neck lateral flexion (P = .64), and neck flexion (P = .53), but there was significant difference for neck extension between the two Groups at the week 0 (P = .04). Left neck lateral flexion was significant difference between the Exercise Group and the Control Group at weeks 4 (P = .001) and 8 (P < .001; time x trial interaction, P < .001; trial effect, P = .01; time effect, P < .001). Right neck lateral flexion was significantly different between the Exercise Group and the Control Group on weeks 4 (P = .01) and 8 (P < .001; time x trial interaction, P < .001; trial effect, P = .04; time effect, P < .001). Neck extension in the Exercise Group was higher than the Control Group at weeks 4 (P = .02) and 8 (P < .001; time x trial interaction, P < .001; trial effect, P = .001; time effect, P < .001). Neck flexion did not significant difference between the two Groups (time x trial interaction, P < .001; trial effect, P = .61; time effect, P < .001). Within-group analyses indicated that, in the Exercise Group, left and right neck lateral flexion were improved over weeks 4 and 8 (all, P < .001). In the Control Group, neck right lateral flexion showed a significant difference between baseline and weeks 4 and 8 (all, P < .001). In the Exercise Group, neck extension increased at weeks 4 and 8 (all, P < .001). In the Exercise Group, neck flexion was improved over time at weeks 4 and 8 (all, P < .001). These findings are presented in Table 2.

Table 3. Back Muscle Strength, Hand Grip Strength, Heart Rate (HR), Systolic Blood Pressure (SBP), and Diastolic Blood Pressure (DBP) at weeks 0, 4, and 8 in the Control and the Exercise Group. Data are Presented as Mean ± Standard Deviation.

	Week 0		Week 4		Week 8	
	Exercise (N = 30)	Control (N = 30)	Exercise (N = 30)	Control (N = 30)	Exercise (N = 30)	Control (N = 30)
Back (kg)	126.7 ± 31.9	121.6 ± 20.8	127.2 ± 31.9#	121.7± 20.7	127.8 ± 31.8#	121.8 ± 20.7
Lt. Hand Grip (kg)	36.8 ± 4.8	37.6 ± 3.9	37.1 ± 4.8#	37.8 ± 3.9	37.6 ± 4.7#	37.8 ± 3.9
Rt. Hand Grip (kg)	37.3 ± 4.6	36.7 ± 6.5	37.6 ± 4.6	36.9 ± 6.5	38.1 ± 4.6	36.8 ± 6.5
HR (beat/min)	74.8 ± 4.6	76.1 ± 4.3	74.8 ± 3.6	76.6 ± 3.1	75.4 ± 4.8	76.3 ± 4.1
SBP (mmHg)	125.6 ± 5.5	125.2 ± 4.4	125.0 ± 4.2	125.6 ± 5.5	125.2 ± 4.4	125.0 ± 4.2
DBP (mmHg)	74.8 ± 5.7	75.8 ± 5.7	75.8 ± 5.7*#	77.8 ± 5.8	77.8 ± 5.7*#	75.6 ± 5.4

*Statistically significant difference between the Exercise Group and the Control Group, P < .05.
#Statistically Significant Difference Between Baseline (week 0) and weeks 4 and 8, P < .05.

There were no statistically significant differences between the Exercise Group and the Control Group for back muscle strength (time x trial interaction, P < .001; trial effect, P = .47; time effect, P < .001), left-hand grip strength (time x trial interaction, P < .001; trial effect, P = .66; time effect, P < .001), and right-hand grip strength (time x trial interaction, P < .001; trial effect, P = .51; time effect, P < .001). Back muscle, left-hand grip, and right-hand grip strength were improving over weeks 4 and 8 in the Exercise Group (all, P < .001). These results are presented in Table 3.

There were no statistical differences for heart rate between Exercise and Control Groups at weeks 0 (P= 27), 4 (P = .05), and 8 (P = .48; time x trial interaction, P < .28; trial effect, P = .21; time effect, P < .33). Systolic blood pressure did not significant between exercise and control groups (time x trial interaction, P = .44; trial effect, P = .22; time effect, P = .44). In contrast, diastolic blood pressure significant difference between the Exercise Group and the Control Group at weeks 4 and 8 (all, P < .001; time x trial interaction, P < .001; trial effect, P = .02; time effect, P < .001). Diastolic blood pressure significantly increased over weeks 4 and 8 in the Exercise Group. These findings are presented in Table 3.

The Relation Between Parameters

Baseline measurements were analyzed to examine associations between pain variables and clinical or ergonomic factors within the Exercise Group and the Control Group. In the Exercise Group, the left rhomboid muscle pain was significantly correlated with left lateral flexion (r = - .40, P =.03), right lateral flexion (r = - .48, P = .01), left upper trapezius muscle pain (r = .76, P < .001), and right upper trapezius muscle pain (r = .76, P < .001). In addition, left rhomboid muscle pain showed a non-significant association with left-hand grip strength (r = - .31, P = .09), right-hand grip strength (r = - .27, P = .14), chair height (r = .29, P = .13). Right rhomboid muscle pain was significantly correlated with left lateral flexion (r = .41, P = .03) and showed a trend toward association with right lateral flexion (r = - .31, P = .09), height of chair (r = .26, P = .16), left hand grip strength (r = - .28, P = .14), right hand grip strength (r = .26, P = .17). Neck muscle pain showed a trend toward association with computer monitor height (r = .32, P = .08), and type of computer (r = .26, P = .17). Left trapezius muscle pain also showed a non-significant trend toward association with neck flexion (r = -.28, P = .14).

In the Control Group, baseline neck muscle pain was significantly associated with right rhomboid muscle pain (r = .42, P = .02) and right-hand grip strength (r = .36, P = .049). In addition, neck muscle pain showed trends toward associations with left lateral flexion (r = - .34, P = .07), right lateral flexion (r = - .31, P = .099), left-hand grip strength (r = .33, P = .08), sitting posture (r = - .31, P = .096), chair height (r = .29, P = .12), sitting duration (r = .29, P = .12), neck flexion (r = .28, P = .14). Left trapezius muscle pain was significantly correlated with right rhomboid muscle pain (r = - .41, P = .025) and left-hand grip strength (r = - .37, P = .04). It also showed a trend toward association with neck extension (r = .35, P = .06), left rhomboid muscle pain (r = - .33, P = .07), left lateral flexion (r = - .32, P = .09), sitting duration (r = .28, P = .14). Right trapezius muscle showed trends toward correlated with right rhomboid muscle pain (r = - .32, P = .08), left lateral flexion (r = - .27, P = .15), left hand grip strength (r = -.27, P = .14), and sitting duration (r = .29, P = .12). Left rhomboid muscle pain was significantly correlated with computer type (r = .38, P = .04), chair height (r = .38, P = .04). Right rhomboid muscle tends to correlated with neck extension (r = - .31, P = .098), type of computer (r = .32, P = .09), chair height (r = .32, P = .09).

DISCUSSION

The purpose of this study was to evaluate the effects of a home-based exercise program, comprising upper-body exercises, stretching, and self-massage on muscle pain and neck range of motion in individuals with neck and shoulder pain. The findings indicated that the home-based intervention reduced trapezius muscle pain and improved neck lateral flexion. However, it did not produce statistically significant changes in muscle strength. At baseline, the muscle pain was significantly associated with neck range of motion, hand grip strength, and computer use behavior.

The pain in the neck and upper trapezius muscles was reduced following the home-based exercise intervention in the present study. This finding is consistent with prior research showing that exercise combined with massage and stretching can reduce neck pain (5,28). Similarly, previous studies have reported that neck muscle pain was reduced after home-based exercise (1,14,17,33). Moreover, home exercise combined with self-massage has been suggested to decrease muscle pain, particularly in myofascial pain syndrome (8). Alkan et al. (1) indicate that supervised exercise may be more effective than home-based exercise.

The mechanisms proposed for the present findings may include improvements in muscle strength, local blood circulation, and tissue healing (10). Stretching may also help suppress pain by inhibiting pain-related sensory pathways, including the Golgi tendon organ-mediated mechanisms (23). In addition, massage can reduce muscle pain by promoting blood flow and facilitating muscle relaxation. Collectively, combining upper-body exercise with self-massage and self-stretching may enhance vasodilation and circulation, thus alleviating pain, particularly in the upper trapezius muscle region. Consistent with these results, muscle pain across different anatomical sites showed interrelationships in the present study. For example, the left rhomboid muscle pain was associated with left trapezius muscle pain and neck muscle pain. This pattern aligns with earlier findings that reported associations between neck pain and trapezius muscle pain (4). Furthermore, left rhomboid muscle pain was associated with computer type and chair height, suggesting that workstation-related factors may contribute to symptom persistence or recurrence. Therefore, future studies should examine computer-use behaviors and ergonomic characteristics in more detail to clarify their potential effects on muscle pain. Consequently, the results of this study indicate that a home-based exercise program can inhibit neck and upper trapezius muscle pain in individuals with neck pain, supporting its potential as a practical non-pharmacological intervention.

Neck range of motion, particularly neck lateral flexion, improved following the home-based exercise program compared with the control condition in the present study. This finding is consistent with prior research indicating that home-based exercise enhances neck range of motion (17). Similar improvements have been reported after combining massage with stretching (5). At baseline, neck lateral flexion was associated with muscle pain in the present study, particularly rhomboid muscle pain. Consistent with this, previous work has reported relationships between neck range of motion and shoulder pain (21). Mechanistically, stretching may increase range of motion by improving flexibility and reducing muscular tightness, while massage may facilitate flexibility through enhanced blood circulation and muscle relaxation. Therefore, these findings suggest that the home-based exercise program improved neck mobility, and most notably neck lateral flexion bilaterally potentially through reductions in pain and improvements in soft-tissue extensibility.

In the present study, hand grip strength was significantly associated with muscle pain in several regions, including the rhomboid muscles, the trapezius muscle, and the neck in the Control Group. In the Exercise Group, handgrip strength also showed an overall tendency to be associated with muscle pain. These findings align with a previous study reporting the association between hand grip strength and neck pain (32). Improvements in back and left-hand grip strength were observed in the Exercise Group at weeks 4 and 8. However, no significant differences in muscle strength were detected between the Control Group and the participants assigned to the home-based exercise program. Previous research has shown that resistance training induces muscle strength and muscle hypertrophy (19). One possible explanation for this might relate to the exercise intensity in this study, which may not be enough to enhance the difference in muscle strength. Therefore, there were no differences in muscle strength between the Exercise Group and the Control Group in the present study.

Limitations in this Study

Several limitations should be considered when interpreting the findings of the present study. First, requiring the participants to perform self-massage may have posed practical difficulties, as individuals may not have been able to apply the appropriate pressure to the intended muscle sites consistently. Second, neck pain was assessed using subjective reports without specifying anatomical landmarks or measurement points, which may have introduced variability in the responses. Third, we did not monitor the participants' physical activity levels, training status, or computer-use behaviors. These factors may have influenced both muscle pain and range of motion. Finally, this study did not include separate groups receiving massage, stretching, or exercise in isolation, nor did it allow direct evaluation of the additive effects of these interventions. Therefore, future research should compare a combined home-based exercise program with massage or stretching alone. Moreover, given evidence that muscle pain may increase after certain exercise modalities (27), the future research should apply a home-base exercise protocol designed specifically to reduce the muscle pain score to promote muscle recovery and to support sustained exercise performance.

CONCLUSIONS

The findings of this study indicated that the home-based exercise intervention, which comprised upper-body exercises with muscle relaxation techniques, such as stretching and self-massage was more effective in improving the neck range of motion and suppressing muscle pain in individuals with neck and shoulder pain. Overall, the home-based program may serve as a practical, optional strategy for preventing or mitigating neck muscle pain, particularly among individuals with neck and shoulder pain.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest.

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Effects of Functional Balance Training on Balance and Shooting Accuracy in National Goalball Players

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ABSTRACT

Duangkanjana S, Ku B, Khongprasert S. The purpose of this study was to examine the impact of functional balance training on balance and shooting accuracy in goalball athletes. Goalball is a sport specifically designed for individuals with visual impairments, in which visual information cannot be used to guide movement direction or execute goal-shooting actions. Consequently, the athletes rely heavily on proprioception, postural control, and neuromuscular coordination for successful performance. Balance ability is considered an essential factor influencing movement control and shooting accuracy in goalball athletes. Sixteen national-level goalball athletes were recruited and randomly assigned to either the Control Group (n = 8) or the Experimental Group (n = 8). The Control Group continued regular goalball training and daily activities; whereas, the Experimental Group performed additional functional balance training 3 times per week for 8 weeks alongside regular training. Balance performance was assessed using the Biodex Balance System, and goal-shooting accuracy was evaluated using standardized shooting assessments from multiple shooting positions. The data were analyzed using descriptive statistics and a 2 × 2 mixed-design analysis of variance (ANOVA). After the 8-week training period, the Experimental Group showed enhanced balance ability and superior shooting performance while there were no significant changes were observed in the Control Group. These findings suggest that functional balance training may serve as an effective strategy for improving postural control and shooting accuracy in goalball athletes, and targeted interventions based on these findings may contribute to improved training strategies and enhanced athletic performance.

Key Words: Balance, Goalball, Shooting Accuracy, Visually Impaired Person

INTRODUCTION

Goalball is a sport specifically designed for individuals with visual impairment. A distinctive characteristic of goalball is that athletes are unable to use visual information to guide movement direction or execute goal-shooting actions. Athletes with visual impairment commonly experience deficits in perceptual–motor function and motor fitness that may adversely affect movement control and postural stability. Reduced neuromuscular coordination can impair balance control, despite balance being a fundamental component underlying movement performance in both activities of daily living and sports participation (17). Postural control depends on the integration of sensory information from the proprioceptive system, the vestibular system, and the central nervous system (6). In the absence of visual input, goalball athletes rely more heavily on these systems than sighted athletes. Consequently, deficiencies in postural control may compromise movement execution, directional changes, and the ability to maintain body stability during dynamic sport-specific actions. Furthermore, poor postural stability may negatively affect fundamental movement patterns such as standing, running, and throwing, thereby limiting athletic performance (3).

Goal shooting in goalball involves a sequence of complex movements including approach steps, trunk rotation, weight transfer, and upper-limb force generation. These actions require athletes to maintain stability while coordinating movement under conditions in which visual feedback is unavailable. Makaracı et al. (14) reported significant negative correlations between postural sway parameters and shooting accuracy, indicating that athletes with greater body sway exhibited poorer shooting performance. Specifically, the larger sway area of center of pressure and ellipse area during right-leg stance were associated with lower shooting accuracy.

Current goalball training programs prioritize sport-specific skills. However, many training techniques may inadequately address balance deficiencies, which pose a significant barrier for athletes with visual impairments. Functional balancing training combines balance challenges with coordinated movement patterns that mimic actual sports scenarios, perhaps offering a more effective method for enhancing postural stability, movement control, and shooting performance. Nonetheless, research about the impact of functional balance training on balancing proficiency and shooting accuracy in goalball athletes is scarce, especially studies that focus on training regimens tailored for those with visual impairments. The objective of this study was to examine the impact of functional balance training on balance and shooting accuracy in goalball athletes.

METHODS

Subjects

A total of 18 goalball athletes were recruited for this study. Eligible participants were required to be Thai national goalball athletes classified as visual impairment levels B1–B3, aged between 18 and 35 years, and have at least one experience of participation in a national-level competition or higher within the previous 2 years. Additional inclusion criteria included no history of musculoskeletal injury during the preceding 6 months, a performance exceeding 30 seconds on the Single Leg Stance Test, and no diagnosed underlying medical conditions. Participants were excluded if unforeseen circumstances, such as injury or accident prevented continued participation in the study, or if they voluntarily withdrew or were unwilling to continue participation. Prior to enrollment, all study procedures were explained in detail, and written informed consent was obtained from all participants.

The most closely matched pairs were then randomly assigned into 1 of 2 groups: (a) the Control Group (CON), which continued regular goalball training and maintained their usual daily activities, and (b) the Functional Balance Training Group (FBT), which performed regular goalball training in addition to functional balance training. The study protocol was approved by the Institutional Review Board of the Inter-Institutional Ethics Committee, Set 1, Chulalongkorn University (approval date: October 3, 2024). Informed consent was obtained from all the participants before their enrollment in this study. The CONSORT guidelines were followed Hopewell et al. (8) and the CONSORT diagram (Figure 1) was used to describe the flow of the participants at each stage of the trial.

Procedures

To certify the consistency of outcomes, A blinded evaluator performed the assessments simultaneously and in the same order for both Groups at pre- and post-assessment after the 8-week period. The outcomes were obtained for both Groups (see Figure 1 for the CONSORT flow diagram)

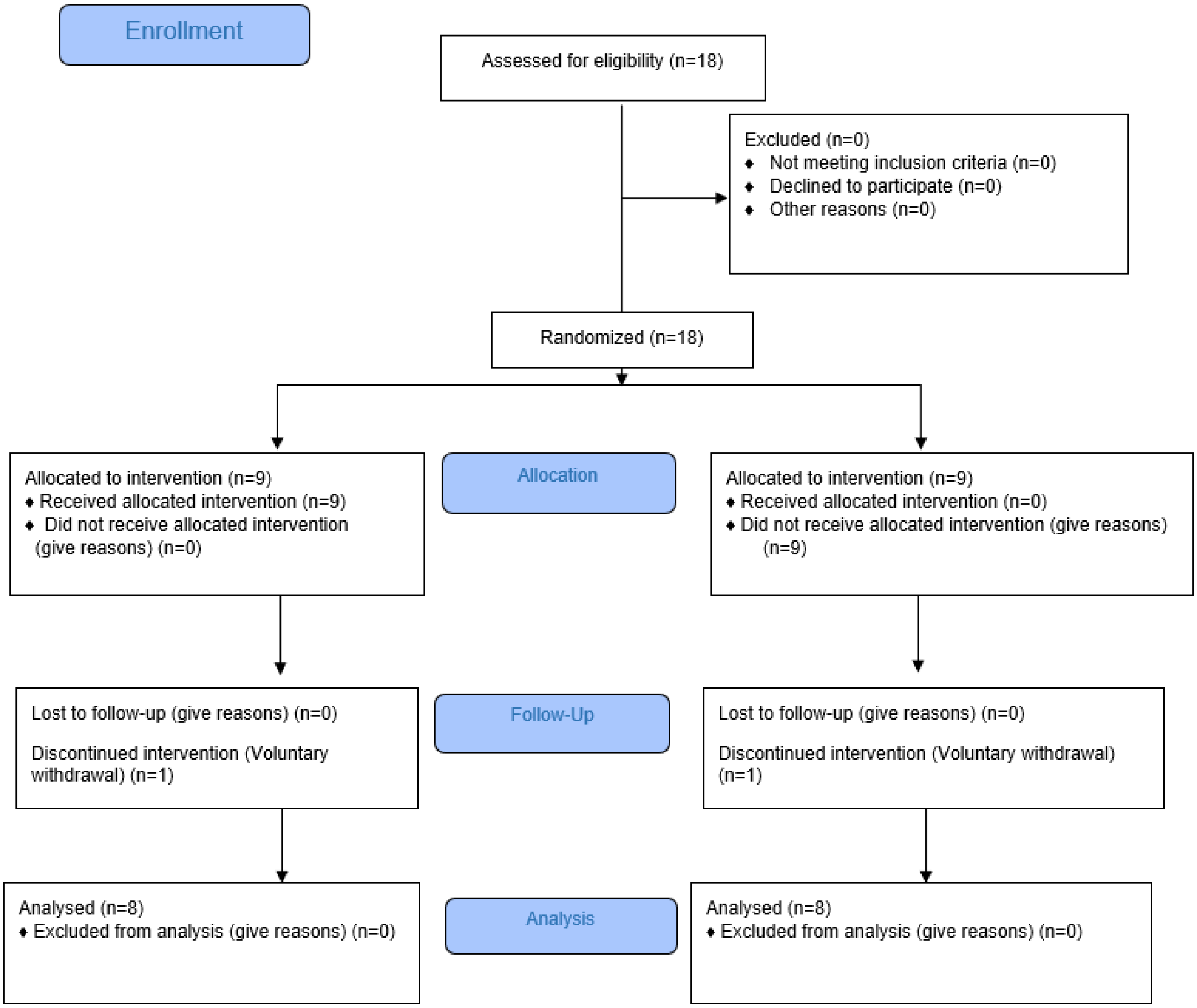

Figure 1. CONSORT Flow Diagram of the Participant's Allocation and Analysis.

Balance Performance

Balance performance was assessed using the Biodex Balance System™ SD (Biodex Medical Systems, USA). The participants performed balance tests under conditions: Double-leg and Single-leg stances on both a firm surface and a foam surface. Each trial lasted 20 seconds, with a 10-second rest interval between the trials and a rest period between the testing conditions. The total duration of the balance assessment was approximately 3 minutes per participant.

Goal-Throwing Accuracy Assessment

Goal-throwing accuracy was evaluated by having the participants perform a total of 9 throws, consisting of 3 throws from the right side (position 1), 3 from the center (position 2), and 3 from the left side (position 3). All throws were executed using the participant's dominant arm, employing both standard throwing techniques and rotational throws (Spin-shot). The throwing distance was set at 12 meters from the goal.

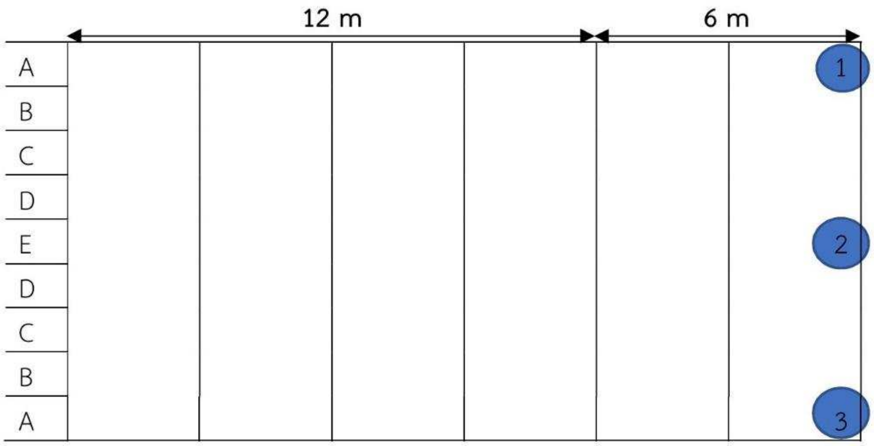

Figure 2. Diagram of a Shooting Accuracy Test.

Before testing, participants were informed of the testing procedures and the scoring criteria. The goal area was divided into 9 equal zones based on the official court width of 9 meters (1 meter per zone), marked clearly on the floor. According to previous research, zones A, C, and D, which represent areas with the highest scoring probability, were awarded 2 points; whereas, zones B and E were awarded 1 point. Throws outside the goal area received 0 points. The total score was calculated from all nine throws. The goal-throwing accuracy assessment required approximately 20 minutes per participant (3).

INTERVENTIONS

The functional balance training program (Figure 3) was specifically designed to be safe and appropriate for athletes with visual impairment. All training was performed under the close supervision of trained assistants, who provided lateral support when necessary to ensure the participants' safety and prevent falls.

The program aimed to enhance postural stability through multidirectional and functional movement patterns. The training incorporated static and dynamic balance tasks, lower- and upper-limb strengthening, core stabilization, and proprioceptive challenges that included the use of an unstable surface (BOSU ball).

Each training session consisted of 12 exercises per day, with 10 repetitions per exercise, performed for 2 sets. The participants completed the program 3 times per week over a total period of 8 weeks.

The training session included tandem stance movements, neck and trunk rotations, jumping and squatting tasks, heel-raise exercises, lunges, ball-handling activities, and core stability exercises (e.g., plank and side plank), performed on both firm and unstable surfaces to progressively increase task difficulty.

Figure 3. Illustration of Functional Balance Training used in the Intervention Program. The Exercises Include Single-Leg Stance, Double-Leg Stance on an Unstable Surface (BOSU ball), Dynamic Weight Shifting with Ball Handling, Overhead Arm Movements, and Core Stability Exercises, Designed to Enhance Postural Control, Neuromuscular Coordination, and Functional Strength in Goalball Athletes.

Statistical Analyses

Statistical analyses were conducted using SPSS software (version 30.0). Descriptive statistics, including means and standard deviations, were used to summarize baseline demographic and general characteristics of the Experimental Group and the Control Group. Normality of the data distribution was assessed using the Shapiro–Wilk Test.

A two-way mixed-design analysis of variance (ANOVA) was performed to examine the effects of group (experimental vs. control), time (pre-intervention vs. post-intervention at 8 weeks), and their interaction on the outcome variables. When the data were not normally distributed, the Wilcoxon Signed-Rank Test was applied. Statistical significance was set at $P < 0.05$.

RESULTS

At baseline (Table 1), no significant differences were observed between the Control and the Experimental Groups for any balance variables. Following the 8-week intervention, significant improvements in balance were observed in the Experimental Group, particularly during standing balance on a firm surface. A significant group × time interaction effect indicated superior balance performance in the Experimental Group compared with the Control Group after training. Improvements were also observed during balance assessment on a foam surface, with both Groups demonstrating reduced sway indices over time. For single-leg stance performance, significant effects were identified in selected conditions, particularly in the anterior/posterior plane; however, improvements were not consistently observed across all balance tasks. Overall, the findings suggest that functional balance training improved specific aspects of balance in the goalball athletes, particularly under the firm surface conditions.

Table 1. Balance Variables Data of the Participants.

Conditions	Control (n = 8)		Intervention (n = 8)	
	Baseline	After 8 weeks	Baseline	After 8 weeks
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
	4/4	4/4	4/4	4/4
Double-Leg on Firm Surface	0.78 ± 0.28	1.39 ± 0.38*†	0.76 ± 0.23	0.54 ± 0.16
Double-Leg on Foam Surface	2.16 ± 0.85	1.47 ± 0.34*	1.97 ± 0.31	0.97 ± 0.41*†
Single-Leg (Dominant Leg) on Firm Surface (OSI)	3.86 ± 1.42	3.90 ± 1.25	3.36 ± 1.12	3.48 ± 0.97
Single-Leg (Non-Dominant Leg) on Firm Surface (OSI)	4.25 ± 1.86	4.18 ± 1.15	3.16 ± 1.04	3.72 ± 1.46
Single-leg (Dominant leg) on foam surface (OSI)	5.85 ± 3.66	5.15 ± 2.06	3.96 ± 2.17	4.33 ± 1.20
Single-Leg (Non-Dominant Leg) on Foam Surface (OSI)	5.62 ± 2.40	4.61 ± 0.56	4.20 ± 1.06	3.60 ± 0.88†
Single-Leg (Dominant leg) on Firm Surface (A/P)	1.78 ± 0.50	3.21 ± 1.14*	2.20 ± 0.79	2.33 ± 0.90
Single-Leg (Non-Dominant Leg) on Firm Surface (A/P)	2.46 ± 1.16	3.10 ± 1.20	1.86 ± 0.74	1.98 ± 0.72†
Single-Leg (Dominant Leg) on Foam Surface (A/P)	3.76 ± 2.06	4.67 ± 2.09	2.86 ± 1.31	3.39 ± 1.09

Conditions	Control (n = 8)		Intervention (n = 8)	
	Baseline Mean ± SD 4/4	After 8 weeks Mean ± SD 4/4	Baseline Mean ± SD 4/4	After 8 weeks Mean ± SD 4/4
Single-Leg (Non-Dominant Leg) on Foam Surface (A/P)	3.52 ± 1.49	3.07 ± 0.99	2.91 ± 0.91	2.92 ± 1.03
Single-Leg (Dominant Leg) on Firm Surface (M/L)	2.91 ± 1.57	2.61 ± 1.55	2.22 ± 0.99	1.79 ± 0.97
Single-Leg (Non-Dominant Leg) on Firm Surface (M/L)	3.13 ± 1.77	2.52 ± 1.34	2.26 ± 1.13	2.44 ± 1.16
Single-Leg (Dominant Leg) on Foam Surface (M/L)	3.90 ± 3.03	2.93 ± 1.21	2.36 ± 1.65	2.71 ± 1.39
Single-Leg (Non-Dominant Leg) on Foam Surface (M/L)	3.91 ± 1.82	3.74 ± 1.23	2.72 ± 0.92	2.47 ± 0.69†

Use the “±” symbol throughout all tables and text presentation of mean ± SD data. Abbreviations: **OSI**; Overall Stability Index, **A/P**; Anterior /Posterior, **M/L**; Medial /Lateral, etc. = Difference within group P < 0.05, **†** = Difference between group P < 0.05

Table 2, following the 8-week intervention, the Experimental Group demonstrated significant improvements in shooting accuracy across standard shooting positions, including the right, center, and left positions. Significant between-group differences were identified after training, indicating superior shooting performance in the Experimental Group compared with the Control Group. For spin-shot performance, a significant improvement was observed only for the right-side shooting position within the Experimental Group; whereas, no significant changes were found for center and left spin-shot conditions. Overall, these findings suggest that functional balance training enhanced shooting accuracy, particularly for standard goal-shooting performance in goalball athletes.

Table 2. Shooting Accuracy Variables Data of the Participants.

Conditions	Control (n = 8)		Intervention (n = 8)	
	Baseline Mean ± SD 4/4	After 8 weeks Mean ± SD 4/4	Baseline Mean ± SD 4/4	After 8 weeks Mean ± SD 4/4
Right-Side Position (Score)	4.25 ± 1.16	4 ± 0.92	3.75 ± 1.16	5.37 ± 0.51*†
Center Position (Score)	3.87 ± 0.99	4.12 ± 0.83	3.75 ± 1.16	5.37 ± 0.74*†
Left-Side Position (Score)	3.37 ± 1.40	4.12 ± 0.83	3.75 ± 1.48	5.50 ± 0.75*†
Spin-Shot Right-Side Position (Score)	3.87 ± 2.10	4.25 ± 0.88	2.75 ± 1.98	4.87 ± 1.12*
Spin-Shot Center Position (Score)	4.62 ± 1.50	4.12 ± 1.24	4.12 ± 1.35	4.50 ± 0.92
Spin-Shot Left-Side Position (Score)	3.50 ± 1.85	3.62 ± 1.18	3.37 ± 1.40	4.50 ± 1.19

* = Difference within group P < 0.05, † = Difference between group P < 0.05

DISCUSSION

Balance

Regarding balance assessed on a firm surface, a significant interaction between time and group was observed. After the intervention, the Control Group exhibited an increased sway index, while the Experimental Group demonstrated superior balance when compared between the Groups. These findings may be explained by the characteristics of the functional balance training program, which included single-leg stance, lateral weight shifting, tandem stance, and tandem stance combined with trunk control and arm and head movements, such as holding a ball in front of the body, to the side, and overhead. These tasks altered the body's center of gravity while simultaneously reducing the base of support, thereby continuously stimulating the proprioceptive system. This stimulation likely enhanced the central nervous system's ability to adapt postural control strategies and reduce postural sway (19).

In stable conditions such as standing on a firm surface, postural control is predominantly regulated through the ankle strategy. Training tasks involving reduced base of support and center-of-gravity displacement may enhance the coordination between ankle and hip strategies, resulting in more effective sway control (9). Moreover, the training exercises contributed to increased strength of the lower extremity muscles, ankle stabilizers, and core muscles that play a crucial role in generating corrective torque for maintaining upright posture. Emphasis on core muscle activation and neuromuscular control enabled the participants to maintain balance more effectively during static balance tasks (15). In contrast, the increased sway index observed in the Control Group following training may reflect insufficient task-specific stimulation of postural control mechanisms compared to the Experimental Group. For goalball athletes, who are unable to utilize visual input for balance regulation, reliance on somatosensory and vestibular systems is critical. Without specific balance-focused training, adaptive capacity to postural demands may decline due to accumulated training load or fatigue, leading to increased postural sway (16).

For balance assessment on a foam surface, no significant interaction between time and group was observed; however, a significant main effect of time was found with both Groups demonstrating reduced sway indices. Standing on foam reduces the accuracy of proprioceptive input from the ankle and plantar surface, thereby increasing reliance on vestibular input and trunk control (10). The Experimental Group performed exercises on unstable surfaces such as a BOSU ball, along with dynamic movements including ball holding, single-leg stance, and core stabilization exercises such as planking. These activities likely enhanced neuromuscular control and core muscle engagement that contributed to the improved sway control. Although the Control Group also exhibited improvements, this may be attributed to the inherent training and competitive experience of goalball athletes, who regularly rely on somatosensory input and body awareness. Such exposure may facilitate learning effects and adaptation to testing conditions even without participation in the intervention. However, the magnitude and pattern of improvement were less pronounced in the Control Group, suggesting that the observed enhancements in the Experimental Group were primarily attributable to the functional balance training program rather than general adaptation or learning effects.

For the single-leg stance test on a firm surface, a significant interaction effect between time and group was observed in the anterior–posterior (AP) stability index of the dominant leg. Within-group analysis revealed that the Control Group demonstrated a significant increase in postural sway following the intervention period; whereas, no significant changes were observed in the Experimental Group. These findings suggest that the functional balance training program may be effective in maintaining balance under challenging conditions, such as single-leg stance. Single-leg postural control requires greater integration of the proprioceptive, vestibular, and neuromuscular systems compared to double-leg stance. In particular, control of AP sway relies on the coordinated activation of ankle and hip stabilizers to rapidly counteract perturbations and maintain balance. This is consistent with findings reported by Khalaj et al. (11). The ability of the Experimental Group to maintain stability may be attributed to neuromuscular adaptations induced by the 8-week functional balance training program, which likely enhanced responsiveness to postural perturbations and improved joint position sense. In contrast, the increased sway observed in the Control Group may be explained by the absence of specific balance-related training. This effect may be more pronounced in goalball athletes, who rely heavily on somatosensory and vestibular inputs due to the lack of visual information. Without sufficient stimulation, these systems may exhibit reduced efficiency over time, leading to diminished postural control, as suggested by Gökşen and İnce (5). Although no significant interaction or time effects were observed for the non-dominant leg, a between-group difference was identified following the intervention. This may be explained by limb dominance, as the dominant leg is generally used more frequently and exhibits superior neuromuscular control, leading to differential training adaptations. In contrast, the non-dominant leg may require a longer duration of training to achieve comparable improvements. These findings are consistent with Paterno et al. (17) who reported that a 6-week neuromuscular training program significantly improved anterior–posterior stability during single-leg stance in adolescent female athletes, with no significant changes observed in the medial–lateral (ML) direction.

For the single-leg stance test on a foam surface, a significant between-group difference was observed only in the ML stability index of the non-dominant leg following the intervention. Although no significant within-group changes were found in the Experimental Group, the observed between-group difference suggests a potential benefit of the functional balance training program in enhancing lateral movement control. This improvement may be attributed to training components involving weight shifting and multidirectional movements, such as single-leg stance and lateral movements. Additionally, the use of unstable surfaces, such as BOSU balls, may have contributed to increased activation of hip and core musculature, as supported by Kurtoğlu et al. (13). The absence of significant differences in other variables may be explained by the challenging nature of single-leg stance on a foam surface, which reduces the accuracy of proprioceptive input from the plantar surface of the foot. Under such conditions, postural control relies more heavily on the vestibular system, ankle and hip stabilizers, and trunk control mechanisms, as described by Allum et al. (1). Therefore, a longer training duration may be required to elicit more pronounced adaptations. Although several variables did not show statistically significant differences, the overall trend of the data suggests that functional balance training plays an important role in maintaining and improving postural control, particularly under highly challenging conditions such as single-leg stance on an unstable surface. In contrast, the Control Group may have experienced a decline in performance due to the absence of specific training stimuli. These findings highlight the importance of task-specific neuromuscular training for optimizing postural control in goalball athletes. This is further supported by Tura et al. (20), who demonstrated that an 8-week BOSU-based training program significantly improved balance performance in athletes.

Shooting Accuracy Variables

Standard Shooting Accuracy

The results of shooting accuracy assessment demonstrated a significant interaction between time and group for the right shooting position. Between-group comparisons revealed significant differences across all 3 shooting positions, while within-group analyses showed that the Experimental Group exhibited significant improvements in shooting accuracy at all positions. These findings indicate the effectiveness of the functional balance training program in enhancing sport-specific skills in goalball, particularly in positions that closely resemble athletes’ habitual movement patterns.

Physiologically, shooting accuracy depends not only on muscle strength but also on postural control, force transmission from the trunk to the upper limbs, and multi-joint coordination. The training program emphasized core muscle engagement through exercises such as wood choppers, Russian twists, planks, and 180-degree rotational movements. These exercises enhanced proximal stability to support distal mobility, thereby improving force transfer and directional control during shooting Kibler et al., (12). Additionally, continuous use of the ball during training may have enhanced proprioceptive input related to object position and weight through joint and cutaneous sensory receptors. This increased sensory input likely improved the nervous system's ability to regulate force and movement direction with greater precision, further contributing to improvements in shooting accuracy.

Although interaction effects were not observed for the center and left shooting positions, this finding may be related to limb dominance. Most athletes preferentially use the right arm for shooting, resulting in greater refinement of force control, directional accuracy, and release timing on the dominant side Barbieri et al. (2). Nevertheless, overall analysis indicated that functional balance training improved shooting accuracy across all shooting positions, reflecting enhanced postural control and movement coordination relevant to goalball-specific skills. These findings are consistent with the study by Hessam et al. (7), which demonstrated that a 12-week core stability training program significantly improved both static and dynamic shooting accuracy in basketball players compared with a Control Group. Collectively, these results support the notion that core stability training effectively enhances shooting accuracy in sports requiring high levels of motor control and postural stability.

Spin-Shot Shooting Accuracy

Spin-shot shooting accuracy showed no significant interaction effect between time and group was observed for the right, center, and left spin-shot positions. However, within-group analysis revealed that the Experimental Group demonstrated a significant improvement in spin-shot shooting accuracy from the right position compared with baseline values. The improvement in spin-shot accuracy from the right position following the 8-week training period may be attributed to neuromuscular adaptations induced by the training program. These adaptations may enhance motor unit recruitment and intermuscular coordination, allowing more efficient control of complex multi-segment movements. In addition, the training program may stimulate central nervous system activity and improve neural signaling to the working muscles, thereby facilitating more efficient muscle activation patterns (21).

The training program used in this study included several exercises involving trunk rotation and ball transfer movements, such as Russian twist with ball, squat twist with ball, and arm swing with ball. These exercises require coordinated activation of multiple body segments, including the core, hip, shoulder, and arm muscles, to generate rotational torque and control ball direction during the release phase. Strengthening the core musculature may therefore improve force transmission through the kinetic chain and enhance movement stability, ultimately contributing to improved sport-specific performance (4). Furthermore, functional balance training may enhance trunk control by improving core stability and dynamic balance, both of which play critical roles in maintaining body stability during rotational movements and ball release. These adaptations may also enhance proprioceptive feedback and sensorimotor control, enabling the neuromuscular system to regulate the timing and sequencing of muscle activation more effectively. Improved sensorimotor integration may therefore contribute to greater precision in force regulation and movement direction during the spin-shot technique. The improvement observed specifically in the right spin-shot position may also be associated with limb dominance. Most of the participants in the present study were right-hand dominant, and right-handed athletes typically perform a counterclockwise trunk rotation before ball release to generate momentum. This rotational pattern may facilitate more effective force generation and directional control during the throwing motion. Alternatively, the absence of significant improvements in the center and left positions may be explained by a potential ceiling effect, whereby athletes may have already demonstrated relatively high baseline accuracy in these positions, limiting further measurable improvement following the intervention. Nevertheless, the findings of the present study suggest that the functional balance training program has the potential to enhance spin-shot shooting accuracy, particularly in movement patterns that correspond with the athletes' dominant side.

CONCLUSIONS

The 8-week functional balance training program, characterized by a variety of functional movement patterns, was safe and appropriate for athletes with visual impairments. The findings demonstrated improvements in shooting accuracy, suggesting that enhanced balance performance may contribute to better sport-specific performance in goalball athletes. Furthermore, targeted interventions based on these findings may contribute to improved training strategies and, consequently, enhanced athletic performance in goalball and other sports requiring precise movement control and postural stability.

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Body Composition Determinants of Cardiorespiratory Responses to Submaximal Exercise in Sedentary Young Adults

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ABSTRACT

Singhasoot N, Boonla O, Padkao T, Chantawong S, Booranasuksakul U, Sukkho O, Roengrit T, Prasertsri P, Chancharoen P. This exploratory cross-sectional study examined the associations between body composition and cardiorespiratory fitness responses to submaximal exercise in 25 sedentary adults (aged 18 to 35 years) who completed anthropometric and body composition assessments using bioelectrical impedance analysis, followed by a submaximal treadmill test based on the Bruce protocol. Cardiorespiratory parameters, including oxygen consumption (VO_2), heart rate (HR), stroke volume (SV), cardiac output (CO), breathing frequency (BF), and energy expenditure (EE) were measured at rest and during exercise. When compared to the resting values, submaximal exercise significantly increased ($P < 0.05$) most cardiorespiratory parameters. Correlation analyses revealed that body weight, muscle mass, total body water, protein mass, mineral mass, and basal metabolic rate were positively associated with VO_2/HR, SV, CO, and EE derived from carbohydrate and protein oxidation (all $P < 0.05$), and negatively associated with BF. In contrast, body fat percentage was positively correlated with BF. Segmental lean mass across all body regions demonstrated similar positive associations with VO_2/HR, SV, CO, and EE while also showing inverse relationships with BF. These findings suggest that lean body composition may be a key determinant of more efficient cardiorespiratory responses during submaximal exercise while higher adiposity may impair ventilatory efficiency.

Key Words: Body Composition, Cardiorespiratory Fitness VO_2, Muscle Mass, Submaximal Exercise

INTRODUCTION

Cardiorespiratory fitness (CRF) is a key indicator of overall health and is strongly associated with cardiovascular function, metabolic regulation, and long-term morbidity and mortality (13,22). Higher levels of CRF are linked to improved aerobic capacity, enhanced oxygen delivery, and oxygen utilization (15), as well as a reduced risk of non-communicable diseases (8). In contrast, low CRF, which is commonly observed in sedentary individuals, is associated with impaired cardiovascular efficiency, reduced metabolic flexibility, and increased cardiometabolic risk (21). Therefore, identifying factors that influence CRF, particularly in physically inactive population, is of considerable clinical and public health importance.

Body composition is a critical determinant of physiological function during exercise. In fact, Vaara et al. (25) indicate that components such as muscle mass, fat-free mass, and total body water contribute to oxygen utilization, cardiac performance, and energy metabolism. Conversely, excess adiposity has been associated with reduced aerobic capacity, impaired ventilatory efficiency, and increased physiological strain during exercise (18). Ebaditabar and colleagues (6) demonstrated that lean mass is positively associated with maximal oxygen uptake (VO_2 max); whereas, body fat percentage (%BF) is often inversely related to CRF (19). However, most of this evidence is derived from maximal or near-maximal exercise testing, which may not reflect the physiological responses encountered during daily activities.

Submaximal exercise testing provides a practical and safe approach to evaluate CRF, particularly in the sedentary or non-athletic populations, since it allows for the assessment of cardiovascular, ventilatory, and metabolic responses under moderate workloads that more closely resemble habitual physical activity. Parameters such as oxygen consumption (VO_2), heart rate (HR), stroke volume (SV), cardiac output (CO), breathing frequency (BF), and energy expenditure (EE) can provide a comprehensive understanding into cardiorespiratory function (20). Despite its relevance, the relationship between detailed body composition indices, including segmental lean mass and fat mass, and cardiorespiratory responses to submaximal exercise remains incompletely understood. In addition, segmental analysis of body composition may offer further insights into regional contributions to exercise performance and physiological responses (7). Differences in lean mass distribution across the upper and lower limbs and trunk may influence hemodynamic responses, ventilatory patterns, and substrate utilization during exercise (10). However, there are limited data available regarding how regional body composition relates to cardiorespiratory responses in sedentary individuals.

Therefore, the purpose of the present exploratory cross-sectional study is to investigate the association between whole-body and segmental body composition parameters and cardiorespiratory fitness responses during submaximal exercise in sedentary young adults. We hypothesized that lean mass components would be positively associated with indicators of cardiovascular efficiency and metabolic activity; whereas, adiposity-related parameters would be associated with less favorable ventilatory and metabolic responses.

METHODS

Subjects

This exploratory cross-sectional study aimed to examine the association between body composition and cardiorespiratory fitness in sedentary individuals. Initially, 28 volunteers were screened using a structured health questionnaire that included a COVID-19 checklist, general demographic information, medical history, and details regarding dietary supplement use, food allergies, smoking, alcohol consumption, and exercise habits. In addition, anthropometric measurements, body composition, blood pressure (BP), HR, and body temperature were assessed.

The ***Inclusion Criteria*** were as follows: (a) male or female participants aged 18 to 35 years; (b) in good health; and (c) without underlying diseases. The ***Exclusion Criteria*** were: (a) body mass index (BMI) ≥25 kg/m² (WHO criteria); (b) regular smoking or alcohol consumption; (c) regular engagement in exercise; (d) regular use of dietary supplements; (e) musculoskeletal or other conditions that could interfere with submaximal exercise testing; and (f) signs of infection or inflammation, such as fever.

Ethical Approval

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Human Research Ethics Committee of Burapha University (Approval No. IRB1-047/2567; approval date: 2 May 2024). The trial was registered at ClinicalTrials.gov (Identifier: NCT06475222; registration date: 7 February 2025). Written informed consent was obtained from all the participants prior to their enrollment in the study.

Procedures

At a subsequent visit, the participants who passed the screening were scheduled to attend the laboratory at the Faculty of Allied Health Sciences, Burapha University, at 8:00 a.m. Prior to the appointment, the participants were instructed to: (a) avoid strenuous activities such as sports training, and refrain from alcohol consumption and smoking for at least 24 hours; (b) avoid tea or coffee for at least 4 hours; and (c) avoid moderate activities such as exercise or household chores for at least 2 hours. In addition, the participants were required to obtain at least 7 hours of sleep on the night before testing.

Upon arrival, the participants rested for 5 to 10 minutes before undergoing sequential assessments of vital signs, body composition, and a submaximal exercise test. To minimize measurement variability, all the assessments were performed by the same researchers under standardized environmental and physiological conditions.

Body Composition Measurement

Anthropometric and body composition assessments were performed using a bioelectrical impedance analyzer (InBody270, InBody Co., Ltd., Daejeon, Korea). The participants were measured in a standing position while wearing minimal clothing. Briefly, the participants stood upright with arms slightly abducted and flexed, feet placed shoulder-width apart, and hands gripping the device handles. Then, the researcher entered the participant information (sex, age, and height), and the measurement was completed within approximately 1 minute (26).

To ensure accuracy, the participants were instructed to void their bladder prior to assessment. They were also advised to empty their bowels, and to refrain from consumption of alcohol and caffeine, smoking, and vigorous physical activity on the day preceding the measurement.

Submaximal Exercise Test

Cardiorespiratory fitness was estimated using the Bruce protocol. The participants performed a continuous, incremental exercise test to volitional exhaustion on a calibrated treadmill ergometer (Lode Valiant; Lode BV, Groningen, the Netherlands) equipped with Lode Ergometry

Manager software (Lode BV, Groningen, the Netherlands). The test began at a speed of 2.7 km·h⁻¹ with a 10% incline for 3 minutes. Thereafter, the workload (speed and grade) was increased every 3 minutes in a stepwise manner until volitional exhaustion was achieved (9). Exhaustion was defined as the onset of maximal dyspnea and fatigue or the inability to maintain the required exercise intensity.

Cardiorespiratory parameters and derived variables included VO_2, HR, ventilatory equivalent for oxygen (VE/VO_2), ventilatory equivalent for carbon dioxide (VE/VCO_2), BF, SV, CO, respiratory exchange ratio (RER), and EE derived from carbohydrate (CHO), fat, and protein oxidation.

Statistical Analyses

All statistical analyses were performed using the SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize participant characteristics. Continuous variables are presented as mean ± standard deviation (SD), along with minimum and maximum values; whereas, categorical variables are expressed as frequencies and percentages. Data normality was assessed using the Shapiro–Wilk Test.

Associations between body composition indices and cardiorespiratory fitness variables were examined using Pearson's correlation coefficients for normally distributed data, or Spearman's rho for non-normally distributed data. A P-value < 0.05 was considered statistically significant. The strength of correlations was interpreted as weak ($r < 0.30$), moderate ($r = 0.30–0.50$), and strong ($r > 0.50$).

RESULTS

Baseline Physical and Physiological Characteristics

Initially, 28 volunteers were enrolled in the study. However, 3 participants were excluded due to a BMI above the Inclusion Criteria (n = 2) and a musculoskeletal condition that could interfere with the submaximal exercise test (n = 1). Therefore, a total of 25 participants completed the study, and their data were included in the final analysis.

There were more females (n = 19, 68%) than males (n = 9, 32%). The mean age, height, systolic BP (SBP), diastolic BP (DBP), and HR were 20.86 ± 0.76 years, 164.21 ± 8.22 cm, 116.75 ± 10.08 mmHg, 70.00 ± 8.28 mmHg, and 76.43 ± 13.31 beats/min, respectively (Table 1).

Baseline Body Composition

Table 1 presents the baseline body composition indices, including body weight (BW), BMI, muscle mass, fat-free mass, total body water, protein mass, mineral mass, %BF, waist-to-hip ratio, visceral fat level, basal metabolic rate (BMR), and fitness score.

Table 1. Baseline Physical and Physiological Characteristics and Body Composition of Participants.

Characteristic/Parameter	Mean ± SD	Minimum	Maximum
Gender (M/F) (n, %)	9/19 (32/68)	-	-
Age (yrs)	20.86 ± 0.76	20	22
Height (cm)	164.21 ± 8.22	153	183
SBP (mmHg)	116.75 ± 10.08	100	136
DBP (mmHg)	70.00 ± 8.28	49	94
Heart Rate (/min)	76.43 ± 13.31	53	104
Body Weight (kg)	57.16 ± 10.48	42.70	83
BMI ($kg \cdot m^{-2}$)	21.07 ± 2.44	17.90	25.90
Muscle Mass (kg)	22.98 ± 5.71	15.60	34.50
Fat-Free Mass (kg)	15.06 ± 5.48	4.40	25.50
Water Mass (kg)	30.83 ± 6.88	21.70	44.70
Protein Mass (kg)	8.28 ± 1.89	5.80	12.20
Mineral Mass (kg)	2.98 ± 0.57	2.15	4.23
Body Fat Percentage	26.43 ± 8.31	8.20	40.40
Waist/Hip Ratio	0.84 ± 0.05	0.76	0.99
Visceral Fat Level	6.07 ± 2.94	1	12
BMR (kcal)	1279.21 ± 201.53	1011	1690
Fitness Score	70.64 ± 4.50	62	82

Data are presented as mean ± standard deviation (SD), minimum, maximum, frequency, percentage. **BMI**; Body Mass Index, **BMR**; Basal Metabolic Rate, **DBP**; Diastolic Blood Pressure, **SBP**; Systolic Blood Pressure. (N = 25).

As shown in Table 2, baseline segmental lean mass and fat mass were assessed for the left arm, right arm, trunk (abdomen), left leg, and right leg regions.

Table 2. Baseline Segmental Lean Mass and Fat Mass of Participants.

Parameter	Mean ± SD	Minimum	Maximum
Lean Mass			
Left Arm (kg)	1.94 ± 0.68	1.15	3.41
Right Arm (kg)	2.00 ± 0.70	1.21	3.54
Abdomen (kg)	17.92 ± 4.76	6.60	27.70
Left Leg (kg)	6.61 ± 1.70	4.33	10.11
Right Leg (kg)	6.65 ± 1.74	4.29	10.39
Fat Mass			
Left Arm (kg)	1.02 ± 0.44	0.20	1.90
Right Arm (kg)	0.98 ± 0.45	0.20	1.90
Abdomen (kg)	7.16 ± 2.98	1.20	12.50
Left Leg (kg)	2.46 ± 0.81	0.90	4.10
Right Leg (kg)	2.47 ± 0.81	1.00	4.10

Data are presented as mean ± standard deviation (SD), minimum, maximum. (N = 25).

Cardiorespiratory Fitness at Rest and in Response to Submaximal Exercise

Table 3 presents cardiorespiratory parameters at rest, including VO_2, VO_2/BW, VO_2/HR, HR, VE/VO_2, VE/VCO_2, BF, SV, CO, RER, and EE derived from CHO, fat, and protein.

In response to submaximal exercise (mean speed: 5.38 ± 1.03 km·h^{-1}), most parameters, including VO_2, VO_2/BW, VO_2/HR, HR, VE/VO_2, BF, SV, CO, RER, and EE for CHO, fat, and protein showed significant changes compared with resting values (all $P < 0.05$).

Table 3. Cardiorespiratory Fitness Parameters at Resting and in Response to Submaximal Exercise Conditions.

Parameter	Resting Condition	Exercise Condition	P-value
VO_2 (mL·min^{-1})	268.00 ± 63.57	1289.64 ± 217.75	<0.001
VO_2/BW (mL·min^{-1}·kg^{-1})	4.96 ± 0.84	28.20 ± 5.36	<0.001
VO_2/HR (mL)	2.96 ± 1.06	9.60 ± 2.55	<0.001
Heart Rate (/min)	91.84 ± 15.94	163.52 ± 20.61	<0.001
VE/VO_2	23.16 ± 3.87	26.85 ± 4.98	0.012
VE/VCO_2	25.00 ± 3.23	24.44 ± 3.50	0.564
Breathing Frequency (/min)	18.24 ± 4.15	37.76 ± 7.61	<0.001
Stroke Volume (mL)	39.34 ± 12.66	59.21 ± 15.76	<0.001
Cardiac Output (L·min^{-1})	3.48 ± 0.79	9.58 ± 2.43	<0.001
RER	0.92 ± 0.08	1.09 ± 0.07	<0.001
CHO EE (kcal·h^{-1})	52.40 ± 20.00	419.96 ± 114.37	<0.001
Fat EE (kcal·h^{-1})	19.00 ± 14.47	3.56 ± 17.80	0.001
Protein EE (kcal·h^{-1})	7.16 ± 1.75	41.92 ± 10.66	<0.001

Data are presented as mean ± standard deviation (SD). **BW**; Body Weight, **CHO**; Carbohydrate, **EE**; Energy Expenditure, **HR**; Heart Rate, **VCO_2**; Carbon dioxide Production, **VE**; Minute Ventilation, **RER**; Respiratory Exchange Ratio, **VO_2**; Oxygen Consumption. (N = 25).

Relationships between Body Composition Parameters and Cardiorespiratory Fitness during Submaximal Exercise

Pearson correlation analysis demonstrated that BW, muscle mass, total body water, protein mass, mineral mass, %BF, BMR, and fitness score were significantly associated with cardiorespiratory parameters during incremental exercise (all $P < 0.05$) (Figure 1). Specifically, BW, muscle mass, total body water, protein mass, mineral mass, and BMR were positively correlated with VO_2/HR (all $P < 0.05$). These variables were also negatively associated with BF, whereas %BF showed a positive correlation with BF (all $P < 0.05$). In addition, BW, muscle mass, total body water, protein mass, mineral mass, and BMR were positively associated with SV and CO (all $P < 0.05$). Furthermore, these parameters were positively correlated with EE derived from CHO and protein oxidation (all $P < 0.05$). Notably, fitness score was positively associated with EE derived from fat oxidation ($P < 0.05$) (Table 4).

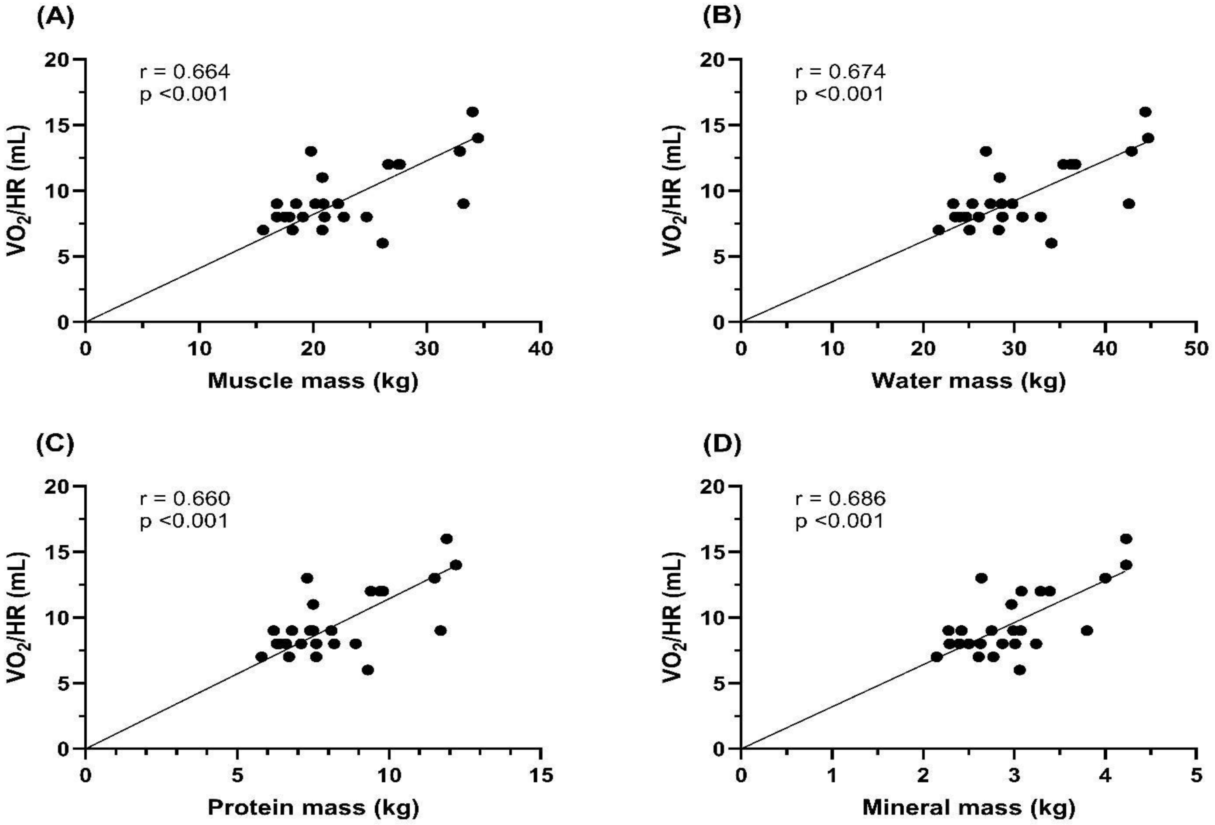

Figure 1. Correlation Coefficients (r) between Oxygen Consumption/Heart Rate (VO_2/HR) and Muscle Mass (A), Water Mass (B), Protein Mass (C), and Mineral Mass (D). Data Points Represent the Value of Each Participant. The Solid Black Line Indicates the Simple Linear Regression Line (N = 25).

Table 4. Correlation Coefficient (r) between Body Composition Parameters and Cardiorespiratory Fitness Parameters in Response to Submaximal Exercise.

Parameter	VO_2	VO_2/ BW	VO_2/ HR	HR	VE/ VO_2	VE/ VCO_2	BF	SV	CO	RER	EE		
											CHO	Fat	Protein
Body Weight	-0.10	-0.14	0.64*	-0.33	-0.32	-0.25	-0.60*	0.63*	0.51*	-0.32	0.45*	0.18	0.51*
BMI	-0.16	-0.35	0.34	-0.38	-0.24	-0.13	-0.28	0.33	0.15	-0.36	0.12	0.09	0.14
Muscle Mass	-0.08	0.07	0.66*	-0.30	-0.34	-0.29	-0.73*	0.68*	0.59*	-0.31	0.49*	0.37	0.59*
Fat-Free Mass	-0.07	-0.37	0.05	-0.12	-0.02	0.02	0.12	0.01	-0.06	-0.08	-0.01	-0.25	-0.06
Water Mass	-0.08	0.08	0.67*	-0.29	-0.34	-0.30	-0.74*	0.69*	0.60*	-0.30	0.50*	0.35	0.60*
Protein Mass	-0.09	0.06	0.66*	-0.30	-0.33	-0.28	-0.73*	0.68*	0.58*	-0.31	0.48*	0.37	0.58*
Mineral Mass	-0.01	0.01	0.69*	-0.30	-0.33	-0.29	-0.72*	0.70*	0.60*	-0.30	0.52*	0.29	0.60*
Body Fat Percentage	-0.06	-0.38	-0.27	0.01	0.14	0.17	0.45*	-0.32	-0.35	0.05	-0.27	-0.34	-0.35
Waist/Hip Ratio	-0.18	-0.29	0.13	-0.06	0.03	0.05	-0.02	0.08	0.07	-0.01	0.07	-0.06	0.07
Visceral Fat Level	-0.03	-0.32	0.04	-0.11	0.01	0.04	0.16	-0.01	-0.08	-0.06	-0.03	-0.27	-0.08
BMR	-0.08	0.07	0.67*	-0.29	-0.34	-0.29	-0.74*	0.69*	0.60*	-0.31	0.50*	0.35	0.59*
Fitness Score	-0.32	-0.10	0.00	-0.25	-0.14	-0.05	-0.22	0.05	-0.08	-0.27	-0.17	0.53*	-0.09

BF; Breathing Frequency, **BMI**; Body Mass Index, **BMR**; Basal Metabolic Rate, **BW**; Body Weight, **CHO**; Carbohydrate, **CO**; Cardiac Output, **EE**; Energy Expenditure, **HR**; Heart Rate, **VCO_2**; Carbon dioxide Production, **VE**; Minute Ventilation, **RER**; Respiratory Exchange Ratio, **SV**; Stroke Volume, **VO_2**; Oxygen Consumption. (N = 25). *, $P < 0.05$.

Moreover, segmental lean mass in the left arm, right arm, trunk (abdomen), left leg, and right leg was positively associated with VO_2/HR, SV, CO, and EE derived from CHO and protein oxidation (all $P < 0.05$) (Figure 2), and negatively associated with BF (all $P < 0.05$). In addition, lean mass in the left arm, right arm, and trunk (abdomen) showed positive correlations with EE derived from fat oxidation (all $P < 0.05$) (Figures 2,3, and 4 and Table 5).

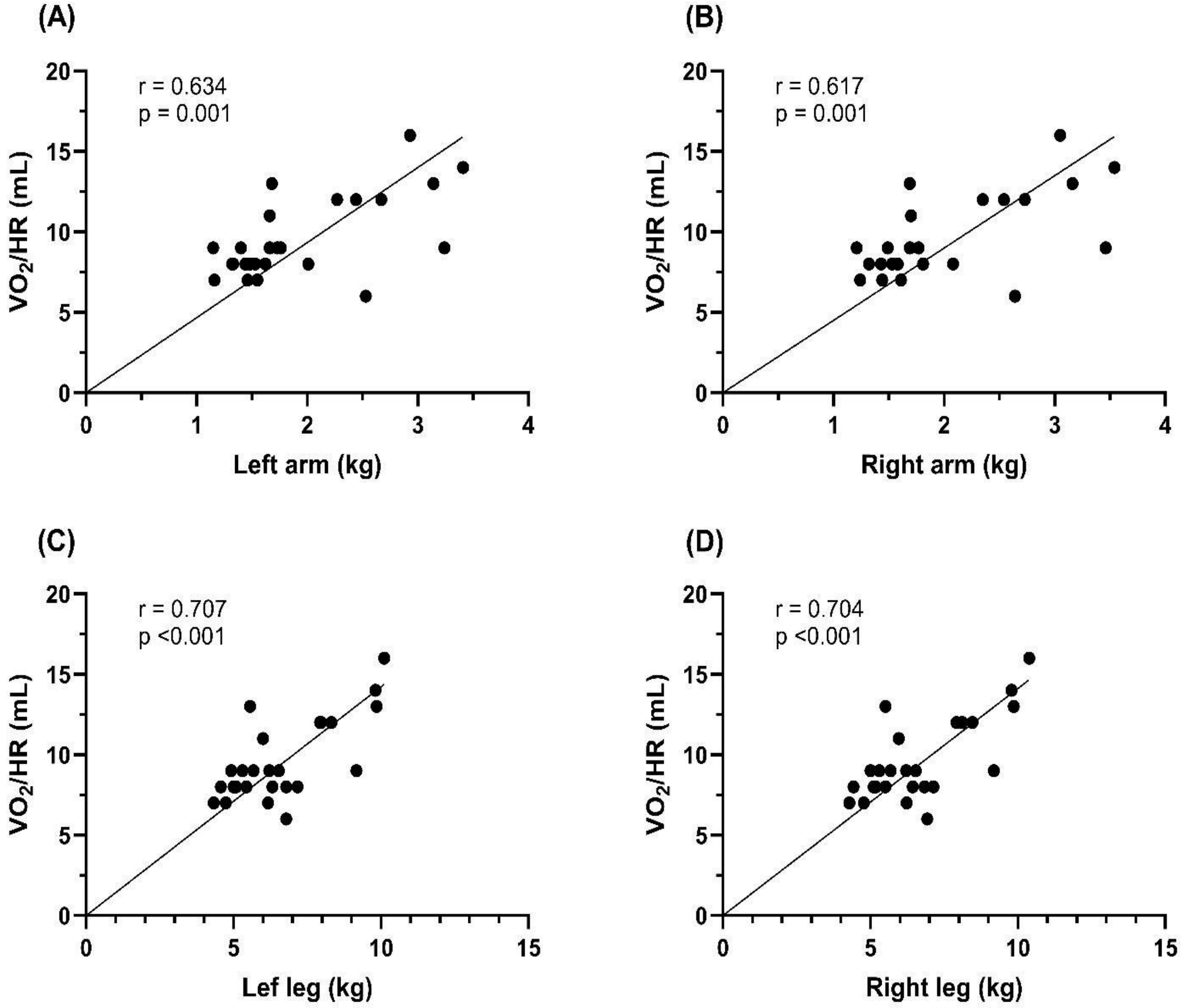

Figure 2. Correlation Coefficients (r) between Oxygen Consumption/Heart Rate (VO_2/HR) and Lean Mass of Left Arm (A), Right Arm (B), Left Leg (C), and Right Leg (D). Data Points Represent the Value of Each Participant. The Solid Black Line Indicates the Simple Linear Regression Line (N = 25).

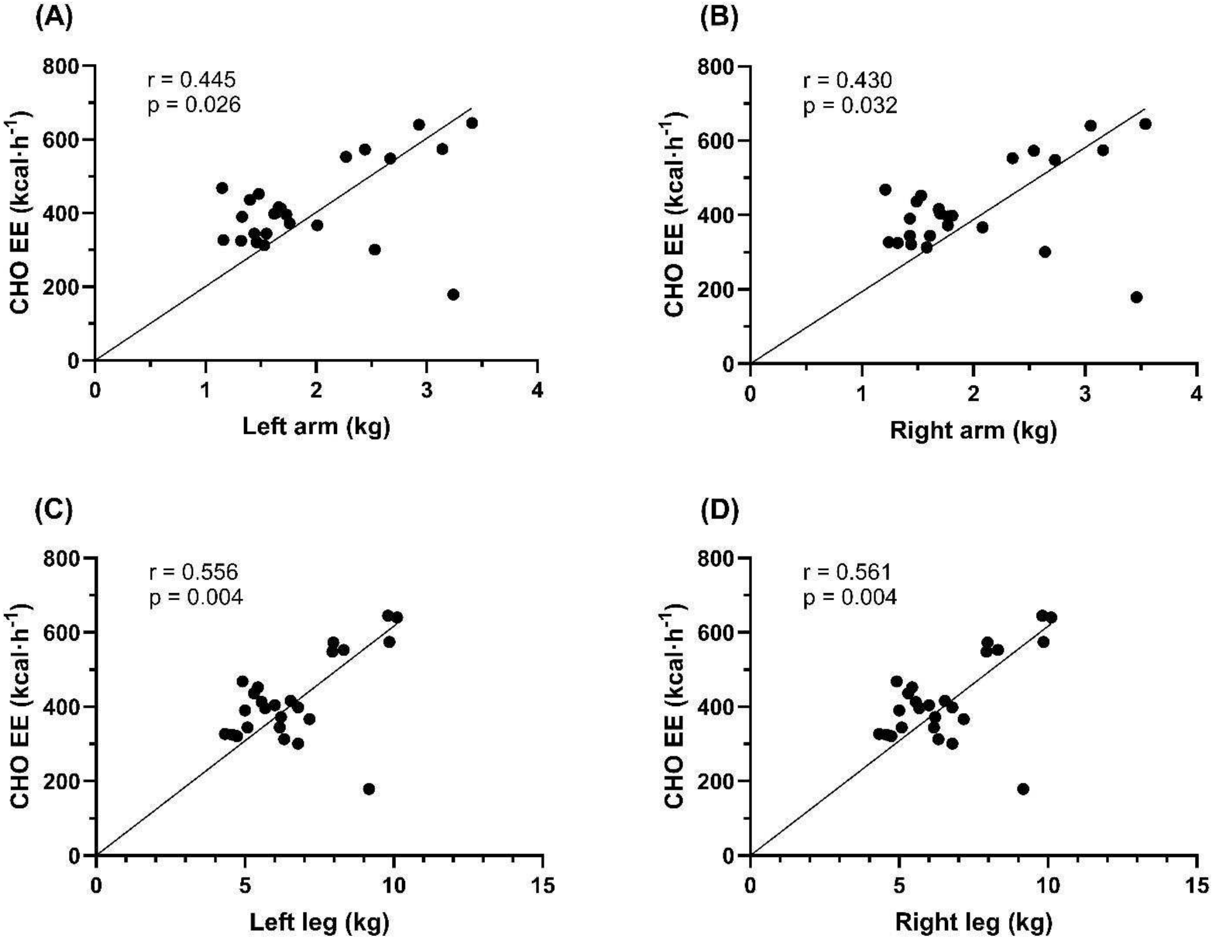

Figure 3. Correlation Coefficients (r) between Energy Expenditure (EE) Derived from Carbohydrate (CHO) Oxidation and Lean Mass of Left Arm (A), Right Arm (B), Left Leg (C), and Right Leg (D). Data Points Represent the Value of Each Participant. The Solid Black Line Indicates the Simple Linear Regression Line (N = 25).

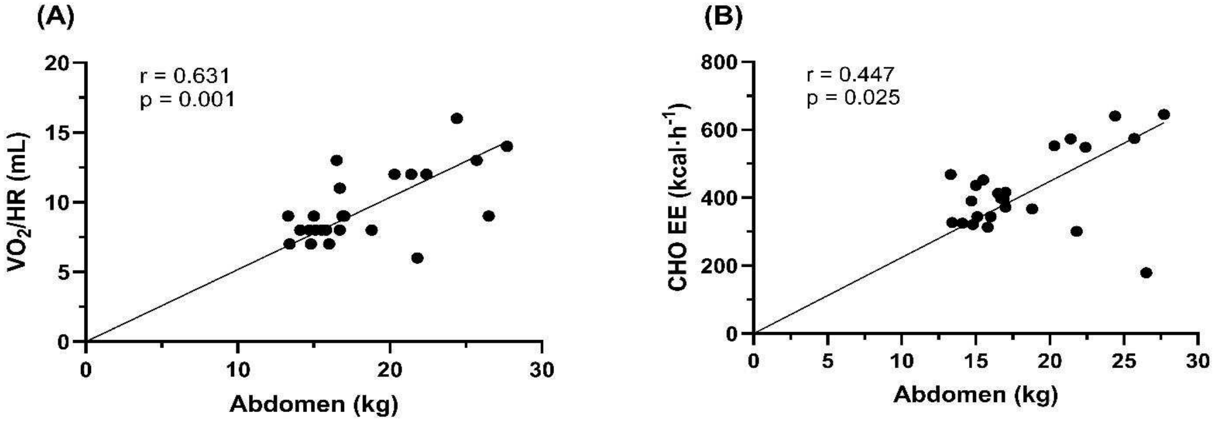

Figure 4. Correlation Coefficients (r) between Lean Mass of Trunk (Abdomen) and Oxygen Consumption/Heart Rate (VO_2/HR) (A) and Energy Expenditure (EE) Derived from Carbohydrate (CHO) Oxidation (B). Data Points Represent the Value of Each Participant. The Solid Black Line Indicates the Simple Linear Regression Line (N = 25).

Table 5. Correlation Coefficient (r) between Segmental Lean Mass and Fat Mass Parameters and Cardiorespiratory Fitness Parameters in Response to Submaximal Exercise.

Parameter	VO_2	VO_2/ BW	VO_2/ HR	HR	VE/ VO_2	VE/ VCO_2	BF	SV	CO	RER	EE		
											CHO	Fat	Protein
Lean Mass													
Left Arm	-0.11	0.05	0.63*	-0.31	-0.36	-0.30	-0.73*	0.65*	0.55*	-0.34	0.45*	0.40*	0.55*
Right Arm	-0.11	0.05	0.62*	-0.31	-0.33	-0.26	-0.71*	0.64*	0.54*	-0.32	0.43*	0.42*	0.53*
Abdomen	-0.09	0.05	0.63*	-0.30	-0.34	-0.28	-0.72*	0.65*	0.55*	-0.33	0.45*	0.40*	0.55*
Left Leg	-0.04	0.14	0.71*	-0.26	-0.35	-0.32	-0.75*	0.72*	0.65*	-0.28	0.56*	0.30	0.65*
Right Leg	-0.03	0.15	0.70*	-0.25	-0.35	-0.32	-0.75*	0.72*	0.65*	-0.27	0.56*	0.30	0.65*
Fat Mass													
Left Arm	-0.01	-0.35	-0.02	-0.06	0.06	0.08	0.22	-0.06	-0.11	-0.01	-0.05	-0.32	-0.11
Right Arm	-0.01	-0.32	-0.05	-0.05	0.02	0.04	0.24	-0.10	-0.14	-0.01	-0.07	-0.34	-0.14
Abdomen	-0.11	-0.38	0.11	-0.13	-0.02	0.02	0.08	0.06	-0.01	-0.08	0.03	-0.23	-0.01
Left Leg	-0.03	-0.36	-0.01	-0.12	-0.04	0.01	0.15	-0.04	-0.11	-0.10	-0.06	-0.25	-0.11
Right Leg	-0.12	-0.34	0.01	-0.12	-0.05	-0.01	0.13	-0.02	-0.09	-0.10	-0.04	-0.26	-0.09

BF; Breathing Frequency, **BW**; Body Weight, **CHO**; Carbohydrate, **CO**; Cardiac Output, **EE**; Energy Expenditure, **HR**; Heart Rate, **VCO_2**; Carbon dioxide Production, **VE**; Minute Ventilation, **RER**; Respiratory Exchange Ratio, **SV**; Stroke Volume, **VO_2**; Oxygen Consumption. (N = 25). *, $P < 0.05$.

DISCUSSION

This exploratory cross-sectional study investigated the relationships between body composition and CRF responses to submaximal exercise in sedentary young adults. The main findings indicate that lean-related body composition parameters, including BW, muscle mass, total body water, protein mass, mineral mass, and BMR were positively associated with indices of cardiovascular efficiency (VO_2/HR, SV, and CO) and EE, while being inversely associated with BF. In contrast, %BF showed an opposing pattern, with a positive association with BF. Furthermore, segmental lean mass across all body regions demonstrated consistent associations with improved cardiorespiratory responses during exercise.

The observed positive relationships between lean mass–related parameters and VO_2/HR, SV, and CO suggest that individuals with greater lean tissue may exhibit enhanced cardiovascular efficiency during submaximal exercise. VO_2/HR is commonly interpreted as a surrogate of oxygen pulse and reflects the combined influence of SV and peripheral oxygen extraction (2). Thus, higher values may indicate more effective oxygen delivery and utilization. Similarly, greater SV and CO responses in individuals with higher lean mass may reflect improved cardiac function and circulatory capacity (3). These findings are consistent with the previous literature demonstrating that fat-free mass and muscle mass are key determinants of aerobic performance and cardiovascular function (12), which are likely due to the increased metabolic demand and enhanced capillary density within skeletal muscle (23).

The inverse relationship between lean mass and BF further supports the notion of improved ventilatory efficiency. Lower BF at a given workload may reflect more efficient gas exchange and reduced ventilatory demand (5) that are potentially due to better oxygen extraction and utilization at the muscular level (4). Conversely, the positive association between %BF and BF suggests that higher adiposity may impose greater ventilatory demands during exercise (16).

This may be explained by the increased mechanical load on the respiratory system, reduced lung compliance, or altered ventilatory control, all of which can contribute to the less efficient breathing patterns (27).

In terms of metabolic responses, lean mass–related parameters were positively associated with EE derived from CHO and protein oxidation; whereas, fitness score was positively associated with EE derived from fat oxidation. These findings suggest that individuals with greater lean mass may exhibit higher overall metabolic activity during exercise (24), particularly in relation to CHO utilization, which is the primary fuel source during moderate-to-high intensity exercise (17). The association between fitness score and fat oxidation aligns with the concept that better cardiorespiratory fitness is linked to enhanced metabolic flexibility and a greater capacity to use fat as an essential source during exercise (28).

Importantly, the present study extends the existing knowledge by incorporating segmental body composition analysis. Lean mass in the upper limbs, trunk, and lower limbs was consistently associated with favorable cardiorespiratory responses, including higher VO_2/HR, SV, CO, and EE, and lower BF. These findings suggest that regional lean mass distribution contributes to systemic physiological responses during exercise (11). Notably, lean mass in the trunk and upper limbs was also associated with greater fat oxidation, which may reflect differences in muscle fiber composition or regional metabolic activity (1). In contrast, segmental fat mass showed limited or no significant associations with most cardiorespiratory parameters that further emphasizes the functional importance of lean tissue over adiposity in determining exercise responses (14).

Limitations in this Study

Despite the findings in this study, several limitations should be acknowledged. First, the cross-sectional design precludes causal inferences regarding the relationships between body composition and cardiorespiratory responses. Second, the relatively small sample size and the predominance of female participants may limit the generalizability of the findings. Third, body composition was assessed using bioelectrical impedance analysis, which, although practical, may be influenced by hydration status and may not provide the same level of accuracy as gold-standard techniques such as dual-energy X-ray absorptiometry. Finally, although submaximal exercise testing provides practical insights, it does not fully capture maximal aerobic capacity.

CONCLUSIONS

This exploratory study demonstrates that lean body composition, both at the whole-body and segmental levels, is positively associated with more efficient cardiovascular, ventilatory, and metabolic responses during submaximal exercise in sedentary individuals. In contrast, higher adiposity may be linked to less favorable ventilatory responses.

These findings highlight the importance of maintaining or improving lean mass to support cardiorespiratory health and exercise performance, particularly in the physically inactive population. Future studies with larger sample sizes, longitudinal designs, and more precise body composition assessments are warranted to confirm these findings and further elucidate the underlying mechanisms.

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