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Original Research Article

Health-Related Benefits of Exercise Training with a Sauna Suit: A Randomized, Controlled Trial

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Abstract

Purpose: Worldwide, the prevalence of overweight and obesity has more than doubled in adults. This epidemic is associated with many cardiovascular and metabolic disorders. Training strategies exist for weight reduction, one of which is heat stress. Evidence has shown that exercise combined with heat therapy provides cardiovascular health benefits. Research is lacking on the use of a heat stress on health parameters for overweight or obese individuals. The purpose of this study was to quantify the effect of health-related benefits associated with exercise training using a sauna suit in a cohort of overweight and obese individuals. **Methods:** Overweight or obese, sedentary, but low risk men and women (n=45) were randomized to the non-exercise control group or one of the two training groups. Exercise training was five days a week for eight-weeks. Monday, Wednesday, and Friday were 45 minutes long training sessions at a moderate intensity based on an individual's heart rate reserve (HRR). Tuesdays and Thursdays were 30 minute long spin classes at a vigorous intensity based on an individual's HRR and were instructed by the principle investigator. **Results:** 45 men and women completed the study. After eight-weeks, $\dot{V}O_2max$ increased significantly (p<0.05) in the sauna suit with exercise group (ESS) when compared to the exercise alone (E) and control groups. Repeated measures ANOVA also showed a significant (p<0.05) improvement in body mass, body fat, blood glucose, RMR, and fat oxidation in the ESS group when compared to the E and control groups. **Conclusions:** A sauna suit in conjunction with exercise: 1) elicited significantly greater improvements in $\dot{V}O_2max$, and 2) significantly improved obesity associated health parameters, which include: body mass, body fat, blood glucose, RMR, and fat oxidation. The novel findings of the present study suggest that a portable heat stress may improve health parameters in overweight or obese.

Key Words: Cardiorespiratory fitness, Cardiovascular disease, Heat Therapy, Weight loss

INTRODUCTION

In recent years, obesity has become one of the most important health concerns for advancing and developing countries[1]. Worldwide, obesity has contributed to diabetes, cardiovascular disease (CVD), and renal insufficiency and is associated with morbidity and mortality. CVD is the leading cause of death, accounting for 17.3 million deaths per annum, a figure that is projected to grow to more than 23.6 million by 2030[15]. Management of risk factors, that are not hereditary, coupled with good nutrition, weight management, and physical activity can be used as preventative measures in avoiding CVD at an early age or later in life. It has been estimated that 80 percent of premature heart disease can be avoided through positive modification of CVD risk factors[15]. In particular, regular physical activity has been shown to confer a myriad of health benefits, including the prevention of numerous CVD risk factors such as hypertension (HTN), obesity, type 2 diabetes (T2DM), and dyslipidemia[21]. In addition, present research has demonstrated that systemic thermal therapy by regular administration of heat through a variety of methodologies, such as saunas, can also induce a number of advantageous responses in terms of cardiovascular health. Chronic exposure to heat stress has been reported to be associated with a reduced risk of CVD and mortality from all-causes[14]. Additionally, Krause and colleagues[13] reported that heat therapy reduces fasting glycemia, glycated hemoglobin, body weight, and adiposity. There is also evidence that exercise, in conjunction with heat therapy, provides cardiovascular health benefits. For instance, it has been demonstrated that three weeks of post-exercise sauna bathing elicits an improvement in cardiorespiratory fitness, most likely due to an increase in plasma volume[18]. Finally, heat can also be used to enhance the magnitude of excess-post oxygen consumption (EPOC) resulting in raised metabolism and weight loss[5].

Recent research has investigated the effects of exercise training in a sauna suit and the impact it has on EPOC and other health parameters. A study by Van de Velde et al.[20] used 12 well-trained participants in a six-week training program while wearing a sauna suit. The study found significant improvements in cardiometabolic risk factors such as body fat percentage, systolic and diastolic blood pressure, triglycerides, HDL cholesterol, and maximal oxygen uptake. The study supports that exercise prescriptions involving a sauna suit may improve cardiovascular health, cardiorespiratory fitness, and reduction of CVD risk factors, however additional research is lacking on this topic. Acclimatization to heat through systemic alterations include: a decreased sweating threshold, reduced threshold for cutaneous vasodilation, and greater skin blood flow at a given temperature, all of which can be beneficial adaptations for exercise training[3].

Training programs with modest weight reduction (approximately 10 percent or less) in patients with obesity-associated medical complications has been shown to be beneficial for obese individuals with non-insulin dependent diabetes mellitus, HTN, and hyperlipidemia[7]. Additionally, abdominal obesity is associated with a pathological accumulation of visceral fat, resulting in the production of adipokines that lead to insulin resistance and chronic inflammation that underlies obesity related comorbidities[12]. A recent study by Khoo et al.[11] compared the effects of diet- or exercise induced weight loss on chemrin, adiponectin, insulin resistance, and inflammation in obese men. The study found that exercise induced fat mass loss was a more effective strategy than dieting for improving adipokines profile, insulin resistance, and systemic inflammation.

Research is lacking on combining heat stress to a training program to improve health parameters in overweight and obese individuals. To our knowledge this is the first, randomized, controlled study to have investigated the effects of exercise training with a sauna suit on performance and health outcomes in an overweight/obese population. It is plausible that exercise training with a sauna suit may provide overweight and obese individuals and fitness professionals with a more practical and portable heat therapy alternative when compared to other thermal treatments. Therefore, the purpose of this study was to quantify the effect of health-related benefits associated with exercise training using a sauna suit in a cohort of overweight and obese men and women. It was hypothesized that exercise training with a sauna suit would result in significantly greater weight loss and improved cardiovascular health when compared to the exercise alone.

METHODS

Participants

45 overweight or obese participants (men and women) 18 to 60 years of age were recruited to perform an 8 week exercise training intervention. Inclusion criteria for participants consisted of overweight or obese (BMI ≥ 25 kg/m^2 and BMI ≤ 40 kg/m^2), sedentary individuals who were low-to-moderate risk as defined by the American College of Sports Medicine (ACSM) guidelines[16], with body fat percentages that were suboptimal. Nonessential fat, above the minimal amount, is generally accepted as 10-22 percent for men and 20-32 percent for women for good health[16]. Anything fat beyond this percent is considered suboptimal. Exclusion criteria included those who were high risk due to cardiovascular, pulmonary, and/or metabolic disease and those who did not have a BMI ≥ 25 kg/m^2 or a BMI ≥ 40 kg/m^2. In addition, a PAR-Q and Health History Questionnaire were administered to screen any high-risk individuals. Prior to baseline testing, participants signed a written

informed consent. The Institutional Review Board at Western State Colorado University approved the study [HRC2017-01-01R29].

Randomization and Intervention

The intervention consisted of three groups: exercise with a sauna suit (ESS), exercise alone (E), and the control. Participants were assigned either the ESS provided by Kutting Weight (Kutting Weight, Van Nuys, CA) or the E group via computerized randomization after being matched for sex and body fat percentage with another participant. The control group was a cohort of individuals who met the inclusion criteria and came only for health parameter measurements but were not asked to workout or change their daily behaviors. Refer to *Figure 1*. Both the exercise in the sauna suit and exercise groups performed similar frequency, duration, and intensity for their exercise prescription. The intervention consisted of five exercise bouts per week with three days at a moderate intensity for 45 minutes and two days at a vigorous intensity for 30 minutes. Refer to *Figure 1*. Additionally, each participant was able to miss 10 days of training without being eliminated from the study and were asked to record each workout in an exercise training log. Participants were also instructed to maintain their usual dietary habits and not perform other exercises or physical activity outside the prescribed study. Modalities prescribed for moderate intensity days varied from the elliptical, rower, and treadmill depending each participant's limitations and fitness level. The two days per week of vigorous exercise were met by attending a spin class led by the principal researcher, where heart rate was monitored to assure that correct intensities were performed. Exercise progression throughout the 8-week intervention was calculated using a heart rate reserve range that increased weekly to reach ASCM guidelines[16] for overweight and obese adults. Refer to table 2. Finally, all exercise prescriptions were completed in the Mountaineer Field House in Gunnison, Colorado (2346.96m).

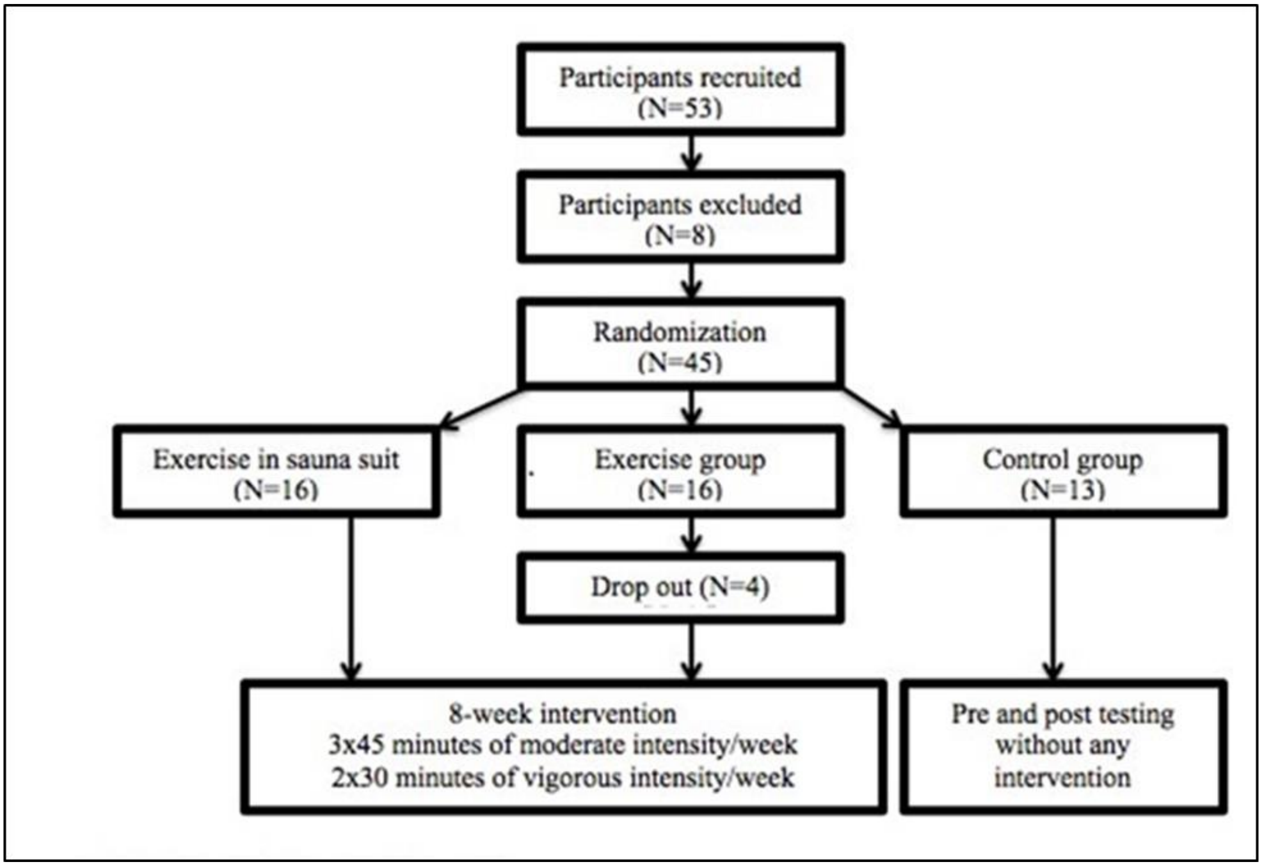

Figure 1. Flow chart of experimental procedures and intervention.

Table 1. 8-week exercise progression: Monday, Wednesday, Friday- elliptical, rower, and treadmill; Tuesday, Thursday: spin bike

	Monday		Tuesday		Wednesday		Thursday		Friday	
week	**min**	**intensity***	**min**	**intensity***	**min**	**intensity***	**min**	**intensity***	**min**	**intensity***
1	30	40-45	20	60-65	30	40-45	20	60-65	30	40-45
2	35	45-50	25	60-65	35	45-50	25	60-65	35	45-50
3	40	50-55	30	65-70	40	50-55	30	65-70	40	50-55
4	45	50-55	30	65-70	45	50-55	30	65-70	45	50-55
5	45	50-55	30	70-75	45	50-55	30	70-75	45	50-55
6	45	50-55	30	70-75	45	50-55	30	70-75	45	50-55
7	45	50-55	30	70-75	45	50-55	30	70-75	45	50-55
8	45	50-55	30	70-75	45	50-55	30	70-75	45	50-55

*intensity prescribed as % of heart rate reserve (HRR).

Experimental Design

Baseline, midpoint, and post-program experimental testing procedures

Assessments of all primary and secondary outcome variables were measured both before and after the 8-week exercise intervention. The primary outcome variables consisted of weight, body composition, fat metabolism, resting metabolism, and anthropometric measures. Secondary outcomes included: resting heart rate (RHR), blood pressure (BP), VO_2max, fasting blood lipids and glucose. All measurements were obtained following standardized procedures outlined from American Council on Exercise (ACE) and ACSM guidelines[16,19]. Descriptions of procedures for each measurement are outlined below. All post program testing was completed within 1 week after the 8-week intervention. Additionally, a Physical Activity Enjoyment Scale (PACES) questionnaire[10] was administered post intervention to assess the intervention group's view of the exercise prescription.

Protocols

Anthropometric measurements

All participants were weighed to the nearest 0.1 kg on a medical grade scale and measured for height to the nearest 0.5 cm using a stadiometer (Tanita, Tokyo, Japan). Prior to these measurements individuals were asked to remove shoes and wear light clothing for pre/post assessments to ensure accurate readings. Percent body fat was assessed via skinfold. Skinfold thickness was measured to the nearest ±0.5 mm using a Lange caliper (Cambridge Scientific Industries, Columbia, MD). A three-site method was used for men and women, standardizing all measurements to the right side of the body. All measurements were performed until two were within 10% of each other. Body composition determined from skinfold thickness measurements correlates well (r = 0.07-0.09) with body composition. Dr. Andrew Jackson and M. L. Pollock provided the research that give a value for body density and percent body fat from skinfold and girth circumference measurements. They found that once body density is calculated, the level of body fat can be determined using the Siri Equation[16]. Waist circumference was determined using a spring loaded-handle cloth tape (Creative Health Products, Ann Arbor, MI) around the narrowest point of the torso (below the xiphoid process and above the umbilicus). Three measurements were taken to insure 2 were within 0.5 mm of each other.

Resting metabolic rate and fat metabolism

Resting metabolic rate (RMR) was measured via indirect calorimetry to represent the amount of energy expended by an individual at rest. Participants were connected to the Oxycon mobile metabolic system (CareFusion Respiratory Care, Yorba Linda, CA) and were asked to rest quietly for 30 minutes before measurements commenced. Participants were also asked not to consume alcohol 24 hours prior to the test, eat at least 4 hours prior to the test, consume caffeine at least 3 hours prior to the test, or consume nicotine 1 hour prior to the test. A 10-minute test was completed, with the first 5 minutes discarded and the remaining 5 minutes representing of RMR and fat oxidation.

Resting heart rate and blood pressure measurement

When measuring RHR participants were asked to remain seated quietly for 5 minutes in a chair with their feet flat on the floor and an arm supported at heart level[16]. RHR was obtained through palpation of the radial artery recording the number of heartbeats for 15 seconds and multiplying said number by 4. BP was measured using a sphygmomanometer (Medline, Mundelein, IL) around the brachial artery and a stethoscope was used to listen for Korotkoff sounds, averaging 3 measurements bilaterally for validity.

Maximal exercise testing

All participants performed a modified-Balke, pseudo-ramp graded maximal exercise test (GXT) pre- and post-program on a motorized treadmill (Powerjog GX200, Maine, USA). Depending on fitness level, participants walked or jogged at a self-selected pace. Grade increased every minute by 1% until the participant reached a point of volitional fatigue. Before each GXT, the metabolic analyzer was calibrated to meet the known gases concentrations of 14.01 ± 0.07% O_2, 6.00 ± 0.03% CO_2. Volume calibration of the pneumotachometer was done using a 3-Litre calibration syringe system (Hans-Rudolph, Kansas City, MO, USA). Gas exchange was measured during the test using the Parvo Medics metabolic cart (Parvo Medics, Sandy, Utah). During the test, the participants wore a Polar heart rate monitor (Polar, Lake Success, NY) and measurements were taken every minute. Exercise blood pressure was also measured during the VO_2max, using an arm cuff (American Diagnostic Corporation, Hauppauge, New York) and stethoscope (Littmann, St. Paul, Minnesota). Participants were asked to rate their rating of perceived exertion (RPE) 10-point scale during the test at the 45-second mark of each minute. After testing, participants went through an exercise cool-down until heart rate was brought to resting. At completion of the test, the last three 15 second increments were averaged to represent the VO_2max value and the highest recorded HR was considered the maximal HR.

Fasting blood lipids and glucose

Prior to blood analyses, participants were asked to fast for 10-12 hours and not consume caffeine. Upon arrival for measurement, participants washed and warmed their hands. Alcohol swabs were then used to clean the finger that got punctured. Lancets were used to puncture the skin and a fingerstick sample was collected using a heparin-coated 40 μl capillary tube. Blood was taken from the fingerstick into the capillary tube without milking the finger. Upon collection of blood, the sample was immediately dispensed into a test cassette for analysis in a Cholestech LDX System (Alere Inc., Waltham, MA). The Cholestech LDX machined measured for low-density lipoprotein (LDL) cholesterol, total cholesterol (TC), high-density lipoprotein (HDL) cholesterol, triglycerides (TG), and blood glucose (BG). Past studies have supported that the Cholestech LDX system has reliability with standard clinical laboratory measurements of plasma lipids and lipoproteins and meets the National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP) criteria for accuracy and reproducibility.

Statistical analyses

Measurements were analyzed using the Statistical Package for the Social Sciences, Version 23.0 (IBM Corporation, Armonk, NY). All variables were initially checked for normality using the Kolmogorov-Smirnov test and were found not to be significant ($p > 0.05$). Measures of centrality and spread are presented as mean ± standard deviation (SD). Paired *t*-tests were utilized to determine pre-post differences within each group. One-way ANOVA were used to compare changes in all primary and secondary parameters between the sauna suit group, exercise group and control group from baseline to post-program. The alpha level of statistical significance was set at $p<0.05$ for all analyses.

RESULTS

For the present study, all analyses and data in the results are for those individuals who completed the eight-week intervention. At baseline, the sauna suit with exercise and exercise group did not differ significantly in physical or physiological characteristics. Refer to Table 2 for physical and physiological characteristics of participants.

Both the E and ESS groups had great adherence for the exercise progression prescribed, with 28 of the 32 participants completing the intervention and 13 participants completing pre and post measurements for the control group. Four participants dropped out during the study for the following reasons: injury outside the study (n=2), illness (n=1), and personal reasons (n=1). It was also noted that during the eight-week study, not a single participant who received the sauna suit intervention dropped out. Overall, there was excellent adherence in both groups, with each participant not missing more than 10 training sessions during the 8 week intervention. Specifically, the ESS group averaged 36/40 (90%) training sessions and the E group averaged 34/40 (85%) training sessions. The control group (n=13) was a group of individuals who came into the laboratory at Western State Colorado University for health parameter measurements. They were not prescribed an intervention and were not asked to workout, for this reason many of their health parameters did not improve or got worse. It is also noted that during the present eight-week study, not a single participant who received the sauna suit intervention dropped out. This indicates the sauna suit was not a factor when it came to participant adherence. Additionally, the PACES questionnaire was administered post intervention and revealed that both the E and ESS training group viewed the exercise training prescription as enjoyable.

Health parameters with no significant improvements after an eight week intervention

After the eight week exercise training intervention, the present study found no significant changes in resting HR, HDL cholesterol, LDL cholesterol, or triglycerides for either the ESS or E group ($p > 0.05$). This is reported in Table 2. Additionally, the PACES questionnaire found no significant difference between the ESS (85.7$\pm$ 6.3) and E (84.7$\pm$ 4.5) group ($p > 0.05$).

Significant improvements with the ESS and E groups compared to the control group

The ESS group showed significantly more improvements in systolic BP (4.2 $\pm$ 3.8 mmHg or ESS vs. -2.0 $\pm$ 0.7 mmHg, control), diastolic BP (3.2 $\pm$ 0.7 mmHg vs. -2.6 $\pm$ 2.4.7 mmHg, control), and total cholesterol (28.8 $\pm$ 22.0 mg·dL^{-1} vs. -6.9 $\pm$ 3.7 mg·dL^{-1}, control) compared to the control group from baseline to eight-weeks ($p < 0.05$) but not in the exercise group. Also, after eight weeks of training, waist circumference decreased significantly ($p < 0.05$ vs. control) in both the E (0.8 $\pm$ 0.2 cm) and ESS (1.7 $\pm$ 0.0 cm) groups compared to the control group.

Effect of sauna suit with exercise after an eight week intervention on $\dot{V}O_2max$

After eight weeks of training, the ESS group had an 11.7 % improvement in $\dot{V}O_2$max compared to only a 7.3 % improvement in the E group. A one-way ANOVA identified a significant increase in $\dot{V}O_2$max in the ESS group compared to the E and control groups [F = 0.91, P <0.05] with the likely range of 0.47 to 4.93%. Refer to Figure 2. Post hoc testing identified that $\dot{V}O_2$max values were significantly higher in the ESS group (4.0 $\pm$ 0.2 mL^{-1} · kg^{-1}·min^{-1}) versus the E group (1.8 $\pm$ 0.2 mL^{-1} · kg^{-1}·min^{-1}).

Effects of sauna suit with exercise after an eight week intervention on body mass and body fat

After eight weeks of training, the ESS group had a 2.6 % reduction in body mass compared to only a 0.9 % reduction in the E group. A one-way ANOVA identified a significant improvement in body mass in the ESS group compared to the E and control groups [F = 0.43, *P* <0.05] with the likely range of -2.4 to -.30%. Refer to *Figure 3.* Post hoc testing identified that body mass values were significantly improved in the ESS group (2.2 $\pm$ 0.1 kg) versus the E group (0.8 $\pm$ 0.2 kg). Additionally, body fat decreased by 13.8 % for the ESS group compared to an 8.3% decrease with the E group. A one-way ANOVA identified a significant improvement in body fat in the ESS group compared to the E and control groups [F = 0.78, *P* <0.05] with the likely range of -3.9 to -.13%. Refer to *Figure 3.*

Post hoc testing identified that body fat values were significantly improved in the ESS group (5.3 ± 1.0 %) versus the E group (3.3 ± 0.2 %).

Effects of sauna suit with exercise after an eight week intervention on fasting blood glucose, RMR, and fat oxidation

After the eight week exercise training intervention, the ESS group had a 7.7 % reduction in fasting blood glucose compared to the E group increasing their blood glucose by 2.1 %. A one-way ANOVA identified a significant improvement with fasting blood glucose in the ESS group compared to the E and control groups [F = 2.7, P <0.05] with the likely range of -15.9 to -2.8%. Refer to *Figure 4*. Post hoc testing identified that fasting blood glucose values were significantly improved in the ESS group (7.5 ± 0.3 $mg \cdot dL^{-1}$) versus the E group actually increasing their fasting blood glucose after the intervention (2.5 ± 21.9 $mg \cdot dL^{-1}$). RMR also improved significantly for the ESS group compared to the E and control groups [F = 0.14, P <0.05] with the likely range of 0.24 to 0.93%. Specifically, RMR improved by 11.4% for the ESS group and decreased 2.7% for the E group. Post hoc testing identified that RMR values were significantly improved in the ESS group (0.4 ± 0.26 $L^{-1} \cdot kg^{-1} \cdot min^{-1}$) versus the E group (0.1 ± 0.2 $L^{-1} \cdot kg^{-1} \cdot min^{-1}$). Finally, the eight week training intervention found that fat oxidation improved by 3.8% for the ESS group and decreased by 2.6%. A one-way ANOVA identified a significant improvement with fat oxidation in the ESS group compared to the E and control groups [F = 0.02, P <0.05] with the likely range of -0.83 to -0.16%. Refer to *Figure 4*. Post hoc testing identified that fat oxidation values were significantly improved in the ESS group (0.3 ± 0.1) versus the E group increasing their fat oxidation after the intervention (0.2 ± 0.01).

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Table 2. Physical and physiological characteristics at baseline and 8wks for control, exercise, and sauna suit with exercise groups. (mean ± SD).

	Control Group (*n*=13, women= 7, men= 6)		**Exercise Group (*n*=12, women= 9, men= 3)**		**ESS Group (*n*=16, women=11, men 5)**	
Parameter	**Baseline**	**8 wk**	**Baseline**	**8 wk**	**Baseline**	**8 wk**
Age (yr)	48.2 ± 8.9	____	52.3 ± 10.6	____	46.7 ± 10.9	____
Height (cm)	169.8 ± 10.9	____	170.6 ± 11.1	____	169.4 ± 9.4	____
Body Mass (kg)	87.2.7 ± 9.3	87.5 ± 9.0	87.5 ± 9.0	90.1 ± 22.1	83.1 ± 13.9	80.9 ± 13.8*‡
Waist Circumference (cm)	90.3 ± 6.7	90.6 ± 7.0	95.6 ± 15.4	94.0 ± 15.4	89.2 ± 10.4	87.5 ± 10.4*†
Body Fat (%)	32.8 ± 5.7	33.5 ± 2.9*	39.9 ± 4.6	36.6 ± 4.4*†	38.3 ± 3.5	33.0± 4.5*‡
Resting HR ($b \cdot min^{-1}$)	65.5 ± 12.1	64.9 ± 8.5	73.1 ± 11.6	69.4 ± 8.1	70.3 ± 10.3	65.6 ± 7.1
Maximal HR ($b \cdot min^{-1}$)	166± 13.1	168.2± 13.1	163.2 ± 14.3	164.2 ± 13.1	169.3 ± 11.7	164.1 ± 3.2
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	30.6 ± 6.1	30.2 ± 5.9	24.8 ± 6.6	26.6 ± 6.4*	34.3 ± 9.0	38.3 ± 9.2*‡
Systolic BP (mmHg)	118.6 ± 9.3	120.6 ± 8.6	123.3 ± 7.2	120.0 ± 7.2*	118.5 ± 9.5	114.3 ± 5.7*†
Diastolic BP (mmHg)	78.0 ± 7.1	80.6 ± 4.7	77.5 ± 4.6	74.5 ± 3.5	75.0 ± 7.3	71.8 ± 6.6†
Total Cholesterol ($mg \cdot dL^{-1}$)	190.2 ± 32.2	197.1 ± 28.5	207.7 ± 32.9	198.3 ± 31.6	222.9 ± 64.1	194.1 ± 42.1†
HDL Cholesterol ($mg \cdot dL^{-1}$)	51.1 ± 21.2	48.9 ± 19.1	57.9 ± 21.6	54.5 ± 20.6	58.4 ± 21.5	52.3 ± 14.0
LDL Cholesterol ($mg \cdot dL^{-1}$)	111.5 ± 28.0	115.7 ± 26.4	125.3 ± 32.9	122.7 ± 34.3	138.6 ± 51.2	115.7 ± 35.0
Triglycerides ($mg \cdot dL^{-1}$)	112.3 ± 41.3	119.1 ± 41.8	121.9 ± 39.1	96.2 ± 30.3	163.1 ± 114.6	130.9 ± 79.7
Fasting Blood Glucose ($mg \cdot dL^{-1}$)	89.1 ± 5.7	89.5 ± 6.8	96.2 ± 8.4	94.8 ± 7.7	96.9 ± 13.4	89.4 ± 13.1*‡
Rest Metabolic Rate ($mL \cdot kg^{-1} \cdot min^{-1}$)	3.9 ± .30	3.9 ± .36	3.7 ± .49	3.6 ± .29	3.5 ± .27	3.9 ± .53* ‡
Fat Oxidation	0.77 ± .05	0.79 ± .04 *	0.78 ± .07	0.80 ± .06	0.79 ± .04	0.76 ± .05*‡

*Within-group change is significantly different from baseline, $p < 0.05$; † Change from baseline is significantly different than control group, $p < 0.05$; ‡ Change from baseline is significantly different than control and E groups, $p < 0.05$.

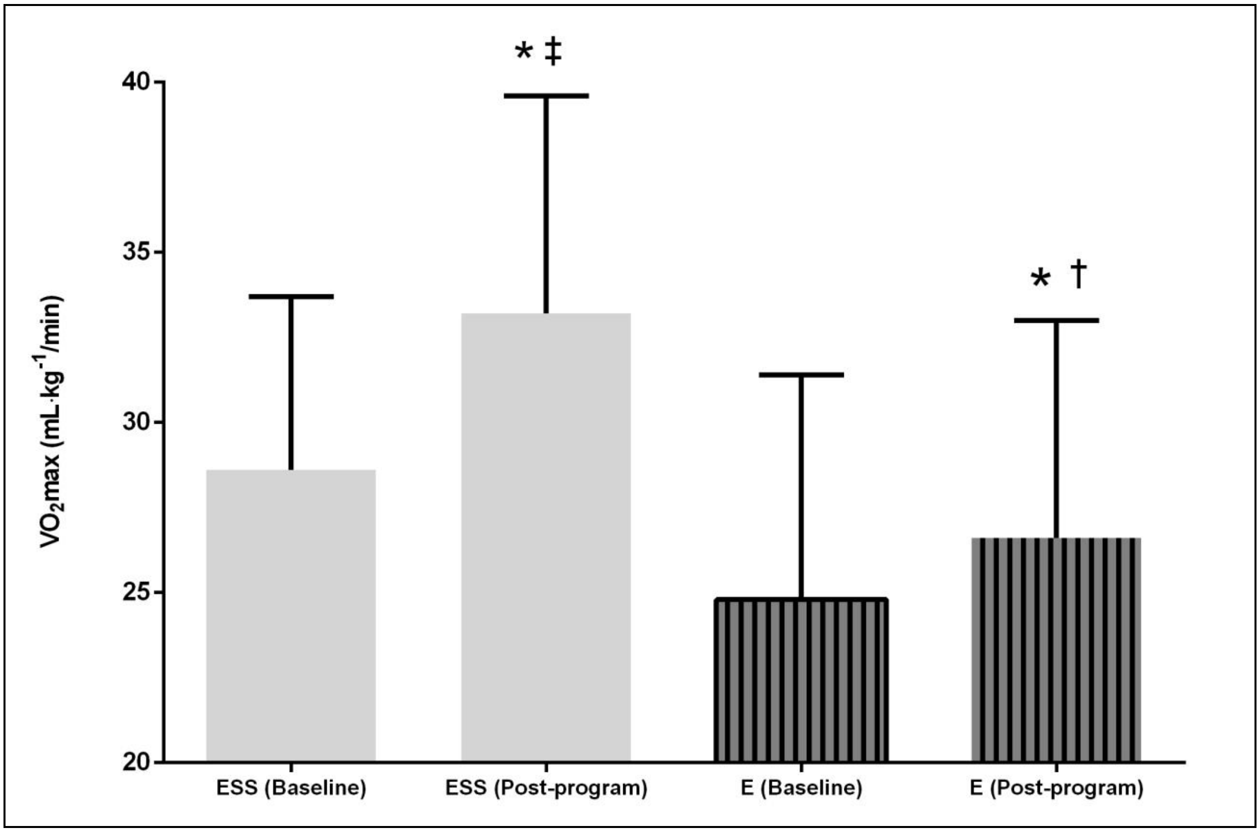

Figure 2. Pre- and post V̇O₂max for exercise with sauna suit (ESS) and exercise alone (E) group. *Within-group change is significantly different from baseline, $p < 0.05$; † Change from baseline is significantly different than control group, $p < 0.05$; ‡ Change from baseline is significantly different than control and E groups, $p < 0.05$

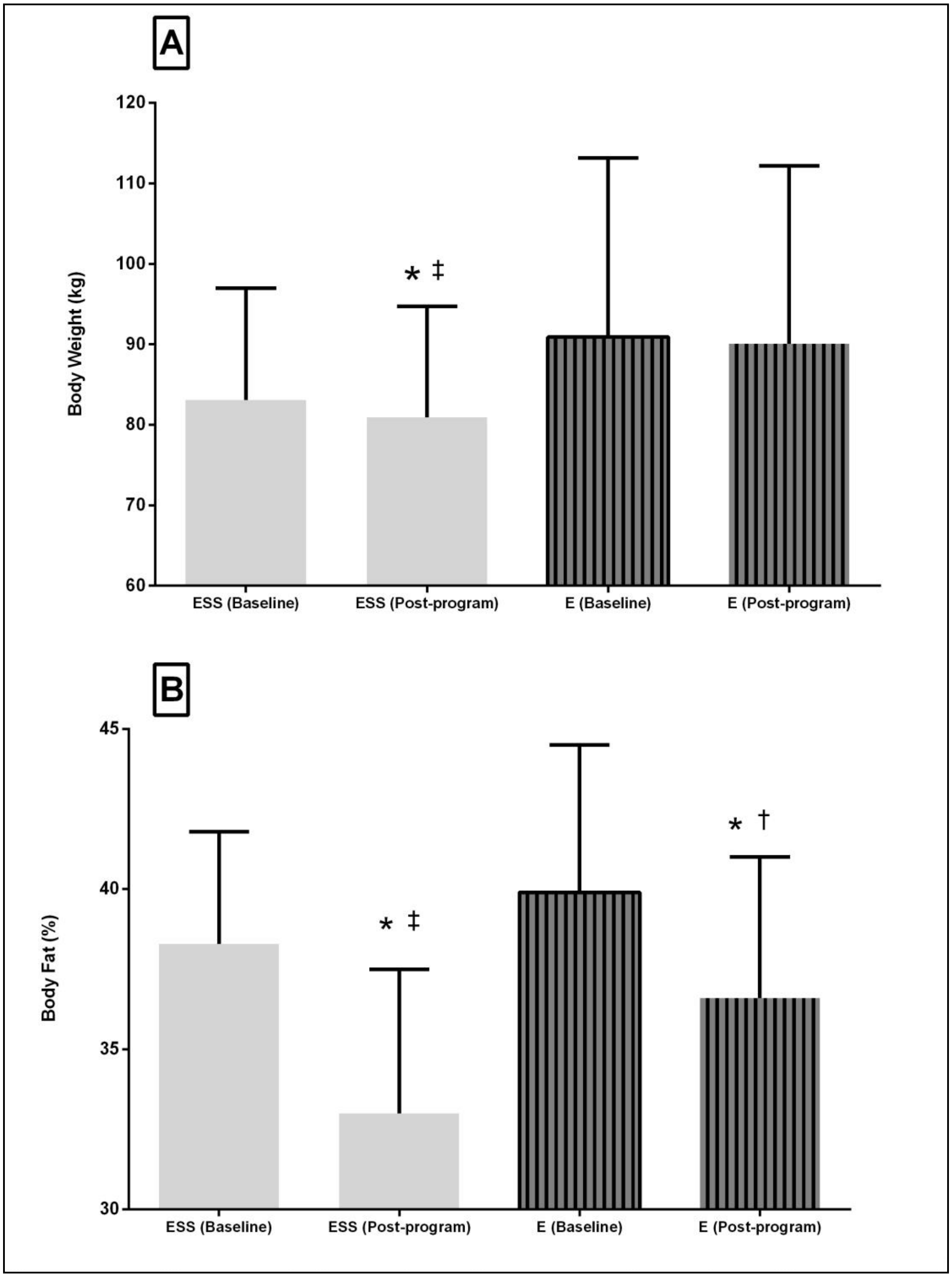

Figure 3. Pre- and post weight (A) and body composition (B) for exercise with a sauna suit (ESS) and exercise alone (E) group. *Within-group change is significantly different from baseline, $p < 0.05$; † Change from baseline is significantly different than control group, $p < 0.05$; ‡ Change from baseline is significantly different than control and E groups, $p < 0.05$.

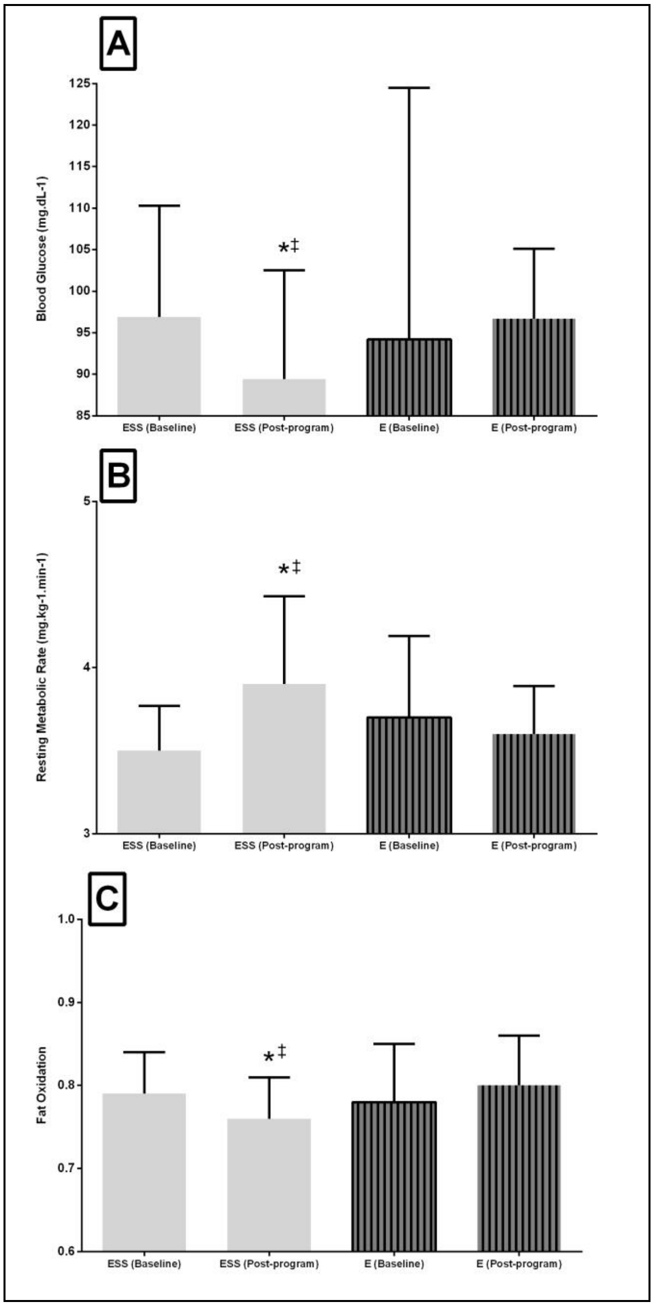

Figure 4. Pre-and post blood glucose (A), resting metabolic rate (B), and fat oxidation (C) for exercise with a sauna suit (ESS) and exercise alone (E) group. *Within-group change is significantly different from baseline, $p < 0.05$; ‡ Change from baseline is significantly different than E group, $p < 0.05$.

DISCUSSION

The major findings of this study were as follows for the ESS group: 1) significant improvement in $\dot{V}O_2max$ when compared to traditional exercise training alone in overweight and obese individuals 2) significant improvements in blood glucose, RMR, fat oxidation, body mass, and body fat in overweight and obese individuals compared to exercise alone. These findings support our hypotheses and justify using a portable heat stress as an exercise training strategy for overweight and obese individuals who are trying to improve health parameters. The results suggest that exercise in a sauna suit can beneficially alter health outcomes in overweight and obese individuals. To our knowledge, this is the first randomized, controlled trial intervention to compare health related benefits of training in a sauna suit versus a traditional exercise program for overweight and obese individuals.

In light of the current overweight and obesity epidemic, the findings of this study are extremely important. This research provides evidence for a portable heat training method that may assist with weight loss and improve health outcomes in the large percent of the world's population who are overweight and obese. Specifically, these findings state that a portable heat stress may elicit favorable health improvements in a cohort of overweight and obese individuals who are working out three times a week at a moderate intensity and two times a week at a vigorous intensity based off HRR. It is noted that for this population that short durations of exercise, like those performed in the present study, are safe when eliciting a heat training adaptation. These findings are important because the exercise prescription in the present study aligns with public health recommendations for overweight and obese individuals[16]. Additionally, the PACES questionnaire demonstrated that the sauna suit was as comfortable as traditional workout clothes for overweight and obese individuals during exercise and did not interfere with the exercise-training program or adherence. Finally, this heat training strategy is affordable and easy to use.

A novel finding from this research was the significant increase in $\dot{V}O_2max$ for the ESS versus E group. It is well established that endurance training intensity is a primary determinant for exercise induced improvements in $\dot{V}O_2max$[16] but the significant increase in the treatment group may have been due to heat stress combined with exercise training. Heat stress has been shown to elicit plasma volume expansion, improved myocardial efficiency, and increased ventricular compliance, which can allow larger end-diastolic volume and greater cardiac outputs[18]. In addition, research has found acclimatizing to the heat to be beneficial for many physiological adaptations, one of which is cardiovascular endurance[18]. These adaptations may explain the significant improvement in $\dot{V}O_2max$ in the ESS group due to a possible increase in maximal cardiac output as a result of plasma expansion. Epidemiological data has also indicated that an elevation in cardiorespiratory fitness is associated with an attenuation of cardiometabolic risk among individuals with MetS, a disease associated with being overweight or obese[9].

The present research suggests that a sauna suit may be an effective method for improving $\dot{V}O_2max$ and performance for individuals who are overweight or obese. In the present study the ESS group improved their $\dot{V}O_2max$ by 11.7 percent versus only a 7.3 percent improvement in the E group. This improvement in cardiorespiratory fitness is important for clinical findings because it is well stated that a low cardiorespiratory fitness might contribute to physiological function and premature death[4]. Additionally, research suggests a 15 percent reduction in mortality for a 10 percent improvement in cardiorespiratory fitness[4].

RMR, fasting blood glucose, and fat oxidation were other health parameters that improved in the ESS group. Physical activity has been shown to significantly affect RMR, which is responsible for the largest component of total energy expenditure throughout the day. Therefore, it makes sense that there was both an improvement in RMR and body composition in the ESS group with the present study. Studies have demonstrated a possible increase in RMR after an exercise-training program resulting in an elevated metabolism, which coincides with the findings of this study. Research demonstrates acute physiological increases in RMR post exercise[5]. These repeated acute adaptations likely underpin the chronic improvements we found in the present study. Our findings show that acute adaptations over an eight week training intervention can result in chronic improvements in RMR for overweight and obese individuals. Additionally, EPOC is also associated with rapid and prolonged rates of elevated metabolism and may have been elicited in the presented study due to vigorous days of exercise bouts above 50-60 percent of $\dot{V}O_2max$. Various factors can influence EPOC such as body temperature, which was increased in the treatment group for the present study[5].

An elevated metabolism and exercise training adaptations may also have played a role in the significant improvement in fasting blood glucose for the ESS group. Research has shown an increase in skeletal muscle glucose uptake during exercise due to increased rates of glucose delivery, surface membrane transport, and intracellular substrates flow through glycolysis[17]. The population for the present study was overweight and obese individuals. These individuals tend to have poor fat oxidation, which results in incomplete beta oxidation. As a result, this causes an inflammatory response and blocks glucose from entering the cell. Additionally, the improvements in insulin-mediated glucose uptake may have been attributed to a training response resulting in increased alternative mechanisms such as an abundance and redistribution of glucose transporter protein (GLUT 4) and other intracellular signaling pathways. This aligns with our findings stating that the improvement in fasting blood glucose in the ESS group may have gone hand in hand with the significant improvement in fat oxidation and an exercise induced training response.

Research has shown that aerobic exercise is more effective in increasing carbohydrate oxidation during exercise, resulting in glycemic control during and after exercise, thus causing increased fat oxidation during recovery[2]. This response may also be associated with EPOC after vigorous exercise training. Vigorous exercise, like that performed Tuesdays and Thursdays in the present study, results in greater neuromuscular activity, muscle mass, and metabolic demand during and after exercise. This may have lead to greater magnitudes of EPOC because of the larger activity of the endocrine and metabolic systems resulting in elevated cardiovascular and respiratory responses. The research mentioned aligns with the findings of the present study, indicating that ESS may elicit increased metabolism, glycemic control, and fat oxidation during recovery by increasing metabolic demand. These findings are extremely important for individuals who are overweight or obese because they may be associated with blood glucose uptake and glycemic control, thus resulting in reduced body fat and improved insulin sensitivity[6,8].

Nonetheless, the present study is not without limitations. The participants consisted of a convenience sample and therefore findings from the present study may not be generalizable to the larger population. Another limitation was that dietary intake and activity/sedentary behaviors outside the training program were not monitored during the eight-week intervention, which could have influenced the current findings. Future research can look into incorporating resistance training into the exercise prescription and trying to control for more behaviors outside of the intervention such as activity/inactivity and dietary intake.

CONCLUSIONS

The results of the present study suggest that a portable heat stress, such as that with a sauna suit, may promote increases in cardiometabolic health and help lower undesirable health parameters associated with being overweight or obese. These findings are important for individuals who are trying to improve glycemic control, reduce body weight, and increase fat oxidation. These novel findings are encouraging for individuals who are trying to improve their health and fitness professionals involved with the prevention of chronic disease.

Competing interests

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