HHS Public Access
Author manuscript
Med Sci Sports Exerc. Author manuscript; available in PMC 2016 September 01.

Published in final edited form as:
Med Sci Sports Exerc. 2015 September ; 47(9): 1950–1957. doi:10.1249/MSS.0000000000000622.

Exercise Training and Energy Expenditure following Weight Loss

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Abstract

Purpose—Determine the effects of aerobic or resistance training on activity related energy expenditure (AEE, kcal/d) and physical activity index (ARTE) following weight loss. It was hypothesized that weight loss without exercise training would be accompanied by a decrease in AEE, ARTE, and non-training physical activity energy expenditure (NEAT) and that exercise training would prevent decreases in free living energy expenditure.

Methods—140 pre-menopausal women underwent an average of 25 pound weight loss during an 800 kcal/day diet of furnished food. One group aerobically trained 3 times/wk (40 min/d), another resistance trained 3 times/wk (10 exercises/2 sets x10 repetitions) and the third group did not exercise. DXA was used to measure body composition, indirect calorimetry to measure resting (REE) and walking energy expenditure, and doubly labeled water to measure total energy expenditure (TEE). AEE, ARTE, and non-training physical activity energy expenditure (NEAT) were calculated.

Results—TEE, REE, and NEAT all decreased following weight loss for the no exercise group, but not for the aerobic and resistance trainers. Only REE decreased in the two exercise groups. The resistance trainers increased ARTE. Heart rate and oxygen uptake while walking on the flat and up a grade were consistently related to TEE, AEE, NEAT, and ARTE.

Conclusion—Exercise training prevents a decrease in energy expenditure, including free living energy expenditure separate from the exercise training, following weight loss. Resistance training increased physical activity, while ease and economy in walking associates with increased TEE, AEE, NEAT, and ARTE.

Keywords

Aerobic training; resistance training; NEAT; exercise economy; exercise ease

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There is not conflict of interest for any of the authors.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Introduction

Obesity continues to be a world-wide problem and participation in physical activity may be one of the preeminent ways to slow or prevent weight gain (21; 39). A number of studies have shown that physical activity is important for maintaining metabolic health independent of weight loss (20; 32) and may be protective during weight regain (3; 11; 36). Despite these well publicized benefits, over 60% of individuals in the U.S. do not meet physical activity recommendations. Although it is well established that total energy expenditure decreases as individuals reduce body size following weight loss, it is unclear whether or not weight loss alters free living energy expenditure with studies showing little change (42) and others showing decreases (29; 41). Resolving this question is important to fully understand the complex relationship between the impact of exercise training during weight loss on free living energy expenditure following weight loss.

Energy expenditure during locomotion varies 10–15% between individuals of similar body mass (17), thus activity related energy expenditure (AEE) and volume of physical activity are different entities, although highly related. We have previously described an objective index derived from a ratio of kcal/day of AEE divided by average kcal/min of net energy expenditure during 5 different locomotion tasks (ARTE index, in minutes/day) (40). The ARTE index may be particularly important for comparing differences in physical activity between individuals or groups that vary in locomotion economy. For example, we have previously shown that aerobic fitness and ease during submaximal locomotion tasks are more strongly related to ARTE index than to AEE in a group of African American and European American women. (17). Given African American women and European American women tend to vary in both locomotion economy/ease and AEE, the standardization for economy enabled the relationship between economy/ease and physical activity to be observed without the confounding effects of economy on AEE.

Aerobic capacity is related to AEE and ARTE as described previously (17). This study also demonstrated that heart rate and perceived exertion during locomotion were inversely associated with AEE and ARTE. AEE includes both energy expended during planned exercise (e.g. aerobic, resistance, yoga, sports) and non-exercise activity thermogenesis (NEAT). It has been shown that NEAT makes up a large proportion of AEE in sedentary individuals (26), can be quite variable (25; 26), and may increase in some individuals in response to overfeeding (25). Thus, it is possible that increasing NEAT is a primary factor that enables an individual to resist weight gain. In contrast, the decrease in AEE (NEAT in non-exercise training individuals) following weight loss (1; 27), may increase the occurrence of weight regain.

Understanding factors that influence participation in physical activity is important. Ease of physical activity is related to increased NEAT (17), while muscle metabolic economy is related to subsequent reductions in weight gain (23). Thus an improved muscle metabolic economy should make physical tasks less demanding and may be an important factor that influences participation in physical activity. Aerobic (14) and resistance training are known to improve locomotion economy (4; 7; 28; 34; 35), ease (4; 7; 28; 34; 35), and endurance (9). Taken together, these data suggest that ease in locomotion may be a critical component that enables individuals to be more physically active. Consistent with this, resistance (18), (10) and combined aerobic and resistance training (10) are two modes of training that increase total and free living energy expenditure.

The purpose of this paper was to determine the effects of aerobic or resistance training during a low calorie weight loss program on AEE, ARTE, and NEAT following weight loss. It was hypothesized that weight loss without exercise training will be accompanied by a decrease in AEE, ARTE, and NEAT but that exercise training will prevent decreases in free living energy expenditure. Additionally, we hypothesized that ease and economy of walking would be related to AEE, ARTE, and NEAT.

Methods

Subjects were sedentary (no exercise training during the prior year) overweight (BMI > 27 and < 30 kg/m^2) women (n = 140) between the ages of 20–44 years. All were tested at baseline after a 4 week weight stabilization period during which the subjects were weighed 3 times/week with food provided during the last 2 weeks. After evaluation they were randomly assigned to one of three groups: 1) Weight loss with aerobic exercise training 3 times/week; 2) Weight loss with resistance exercise training 3 times/week; and 3) weight loss without exercise training. During weight loss, the subjects were provided an 800 kcal diet until reaching a BMI <25 kg/m^2. After weight loss subjects were weight stable for 4 weeks while continuing to have food furnished. Food was provided (20–22% fat, 20–22% protein, and 56–58% carbohydrate) by the General Clinical Research Center (GCRC) Kitchen. Women were admitted to the GCRC 2 days prior to all testing to ensure that physical activity and diet was standardized. Testing was done in a fasted state in the morning after spending the night in the GCRC. The study was approved by the University of Alabama at Birmingham Institutional Review Board and informed consent was obtained from all subjects.

Exercise training

Exercise training occurred in a 1600 square foot exercise training facility devoted to research. All training was supervised by an exercise physiologist and was scheduled to occur 3 times each week. Both aerobic and resistance trainers warmed up with 5 minutes of walking and 3–5 minutes of stretching.

Aerobic Training

Continuous treadmill walking/jogging was used as the mode for aerobic training. Subjects did 20 min of continuous exercise at 67% maximum heart rate during the first week of training. Duration and intensity increased each week so that by the beginning of the eighth week, subjects exercised continuously at 80% of maximum heart rate for 40 minutes. Subjects were encouraged to increase intensity (either speed or grade) when average exercise heart rate was consistently below 80% of maximum heart rate. After the exercise session, subjects cooled down for 3–5 min with gradually decreasing exercise intensity.

Resistance training

The resistance training program included squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower back extension, and bent leg sit-ups. After one week of familiarization (training with a light weight) one repetition maximum (1 RM) was measured. The first week following the 1 RM tests one set of 10 repetitions was performed at 65% 1 RM, with percent of 1 RM increasing on subsequent weeks until week four intensity was at 80% 1 RM. Starting at week five, two sets of 10 repetitions were attempted at 80% 1 RM for each exercise with 2 min rest between sets. Strength was evaluated every five weeks, and adjustments in training resistance were made based on the most current 1 RM in both the weight loss and one-year weight maintenance phases.

Resting oxygen uptake/energy expenditure: Resting oxygen uptake and energy expenditure (REE) was determined in the fasted state between (0600 and 0650) on three consecutive mornings following an overnight stay in the GCRC

Three consecutive mornings in a fasted state and after an overnight stay in the General Clinical Research Center resting oxygen uptake and resting energy expenditure (REE) was determined between 6:00 and 6:50 a.m. Subjects remained awake in a quiet, softly lit, well ventilated room in which temperature was maintained between 22 and 24°C. Subjects laid supine on a comfortable bed and oxygen uptake was measured using a ventilated hood system. After resting for 15 minutes, oxygen uptake was measured for 30 minutes with a computerized, open-circuit indirect calorimetry system (Delta Trac II, Sensor Medics, Yorba, CA, USA). The last 20 minutes was used for analysis. Oxygen uptake values used in the determination of exercise net VO_2 (i.e. exercise VO_2 – resting VO_2) were means of the 3 morning values. The coefficient of variation for repeat VO_2 measures is < 4% in our lab.

VO_2max

A maximal modified Bruce protocol was used to determine VO_2max (8). Heart rate was measured using a POLAR Vantage XL heart rate monitor (Gays Mills, WI, USA). Oxygen uptake and carbon dioxide production were measured continuously using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, NY). Gas analyzers were calibrated with certified gases of known concentrations. Standard criteria for heart rate (heart rate within 10 beats/min of estimated maximum), respiratory exchange ratio (RER above 1.2), and plateauing were used to ensure achievement of VO_2max. The coefficient of variation for repeat measures of VO2max are less than 3% in our lab.

Ease and Economy of Physical Activity

Heart rate (HR), respiratory exchange ratio (RER), and oxygen uptake (VO_2) were obtained during treadmill walk on the flat (4.8 km/hr), and a 2.5% grade treadmill walk (4.8 km/hr). The duration of each of the tasks was between 4 and 5 minutes and steady state was obtained. Oxygen uptake and carbon dioxide production were also measured using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, NY). Net oxygen uptake (work steady state VO_2 minus resting VO_2) is reported in ml O_2/kg/min and is considered exercise economy for walking and stair climbing. HR increases as the intensity of exercise increases. Therefore, HR is considered an index of exercise difficulty.

Strength Measure

Using methods previously described (16), knee extension and elbow flexion strength was measured isometrically. Force was measured using a universal shear beam load cell (LCC 500: Omega Engineering, Stanford, CT, USA). Knee extension maximal force was measured at a knee position of 110° on the right leg at the level of the lateral malleolus. Subjects were restrained across the upper legs and hips with padded straps. Elbow flexion strength was measured in a standing position with the elbow at 110°. Upper arm position was fixed parallel with the torso with a shoulder harness. After three warm-up trials, three maximal isometric contractions were recorded with 60 second rest intervals between trials for both the knee extension and elbow flexion tests. Coefficient of variation for these tests in our lab is less than 3%.

Estimated energy cost of exercise training

Net oxygen uptake (exercise oxygen uptake – resting oxygen uptake) was measured (Max-1 Cart, Physio-Dyne Instrument Corporation, Quogue, NY) while walking at a grade that was within 5 beats/minute of the heart rate that subjects trained during the two week time period that TEE was measured during the post training evaluation (no exercise training was taking place during the pre-training evaluation). Oxygen uptake was measured during the first 5 minutes of exercise, between the 20th and 25th minutes of exercise and between the 35th and 40th minutes of exercise and averaged. Oxygen uptake was converted to kcal/session (5 kcal × liters O_2/min × 40 minutes).

We measured the energy cost of the resistance training and 15 minutes of recovery on a subset of 25 subjects (COSMED K4 b^2 portable metabolic system (COSMED S. r. l., Rome, Italy)). Based on these measured values, we developed a regression equation for estimating energy expenditure for the rest of the subjects based upon the amount of weight lifted in each of the exercises use in the resistance training. We then validated the equation using a different set of older women (n =14) and found that the R^2 between predicted and actual energy expenditure to be 0.95 (standard error of estimate of 11 kcal) using methods we have previously described (22). Actual measured resistance training energy expenditures were used for the 25 subjects that had measured resistance training energy expenditures while estimated energy expenditures were generated from the regression equation for those remaining subjects.

DXA

Dual-energy X-ray absorptiometry (Lunar DPX-L densitometer; LUNAR Radiation, Madison WI) was used to determine total fat and lean mass according to the manufacturer’s instructions. Adult Software, version 1.33, was used to analyze the scans.

TEE

TEE was measured prior to and during the last 2 weeks of resistance training using the doubly labeled water technique as previously described (40). Four timed urine samples were collected after oral dosing of the doubly labeled water: two urine samples were taken in the morning after dosing and two more urine samples were taken 14 days later with a loading dose of 1 gram of pre-mixture (10% $H_2{}^{18}O$ and 8% ^2H_2O) per kilogram of body weight. The isotopic dilution spaces were calculated from the $H_2{}^{18}O$ and ^2H_2O enrichments in the body by the extrapolation of the log enrichments back to zero time using the following equation: Dilution space (liters) = d/20.02 • 18.02 • 1/R • E where: d is grams of $H_2{}^{18}O$ and ^2H_2O given, R is the standard ratio for ^{18}O:^{16}O (0.002005) and ^2H:^1H (0.00015576), E is the enrichment of the $H_2{}^{18}O$ and ^2H_2O at the extrapolated zero time (the % above background). The rate of carbon dioxide production (rCO_2) was calculated from the equation by Schoeller (30): $rCO_2 = 0.4554 \cdot N\ (1.01\ K_0 - 1.04\ K_h)$ where rCO_2 is the amount of CO_2 produced (mol/day) corrected for fractionation, N is total body water (mol) K_0 and K_h are the turnover rates of $H_2{}^{18}O$ and ^2H_2O (days $^{-1}$) respectively. TEE was then calculated from CO_2 production using the equation from de Weir (2): TEE (kcal/day) = 3.9 (rCO_2/ FQ) + 1.1 rCO_2, where TEE is total energy expenditure (kcal/day), rCO_2 is the rate of carbon dioxide production (l/day where 1 mol of CO_2 is equivalent to 22.4 l) and FQ is the food quotient. Samples were analyzed in triplicate for $H_2{}^{18}O$ and ^2H_2O by isotope ratio mass spectrometry at the University of Alabama at Birmingham as previously described (5). Samples for $H_2{}^{18}O$ and ^2H_2O were re-analyzed in seven subjects, the values of TEE between days were in close agreement (coefficient of variation = 4.3%) thus, demonstrating a high level of reproducibility.

AEE, NEAT, PAL

AEE was estimated by subtracting REE from TEE after reducing total energy expenditure by 10% to account for the thermic response to meals. NEAT was calculated as NEAT = AEE − energy cost of exercise training (25). PAL was calculated by dividing TEE by REE.

ARTE

Free living physical activity was determined from AEE using the activity-related time equivalent (ARTE) index (43). The ARTE index (min/d) = AEE/AEC, where AEC is a measure of the steady state net energy cost (energy economy) of performing 5 standardized tasks in the laboratory (walking at 3 mph on the flat, walking at 3 mph while walking up a 2.5% grade, stair climbing (7 inch step) at a rate of 60 steps/minute, carrying a weighted box (30% of maximal isometric elbow strength) while walking at 3 mph on the flat, and riding a stationary cycle at 50 watts). After adjusting for body weight the AEC is a measure of economy of performing the 5 exercise tasks. The exercise tasks were selected to reflect typical activities of women in a free- living environment. ARTE (in minutes/day) is thus an index of the part of the day that the subjects participate in physical activity equivalent to the 5 standardized tasks. The index is particularly useful in comparing AEE values in which energy economy of locomotion may be different, such as following weight loss.

Statistics

Two (time) by two (group) analysis of variance (ANOVA) was run on all variables with repeated measures on time. Bonferroni corrected post hoc T-tests were run on contrasts of interest. Simple Pearson-Product correlations were run between activity-related energy expenditure and physical activity variables and walking heart rate and oxygen uptake variables. SPSS was used for the analyses and α was set at 0.05.

Results

Descriptive variables are contained in Table 1. All subjects decreased weight, BMI, percent fat, fat mass, fat free mass, and elbow flexion strength with weight loss. No significant change in VO_2max when reported in liters/minute was observed ($P = 0.07$). In addition, no significant improvement in knee extension strength was found but there was a significant increase in VO_2max when reported in ml/kg/min. Time by group interactions were observed for percent fat ($p < 0.04$), fat free mass ($p < 0.01$), VO2max (ml/kg/min), VO2max (L/min), and elbow flexion strength ($p < 0.01$) but not knee extension strength ($p = 0.09$). Post hoc analysis revealed that the resistance training group decreased percent fat more than the other two groups and that there was a non-significant increase in elbow flexion strength and knee extension strength compared to the other two groups who decreased strength.

The submaximal walk heart rate and oxygen uptake results are shown in Table 2. Heart rate significantly decreased during the 3 mph walk on the flat, the 3 mph walk up a 2.5% grade, and the average heart rate of the two tasks. Net VO_2 decreased significantly for the 3 mph walk on the flat. No time by group interactions were observed for any variable. However, post hoc tests showed that the resistance training group significantly reduced net VO_2 for the walk on the flat and the average net VO_2 for the level and grade walks.

Energy expenditure and physical activity variables are shown in Table 3. A significant time effect was observed for TEE and REE, while a significant time by group effect was observed for AEE, ARTE, and PAL. Post hoc analyses showed that the no exercise group significantly decreased AEE, NEAT, and ARTE following weight loss. Post hoc analysis also revealed that the resistance training group significantly increased ARTE and PAL while all groups significantly decreased REE.

Tables 4 (overweight) and 5 (post overweight) contain correlations of NEAT and ARTE with heart rate (measure of locomotion ease) and submaximal VO_2 (measure of locomotion economy). In the overweight state, heart rate while walking at 3 mph was significantly related to NEAT (since exercise training was not occurring in the overweight state AEE and NEAT are identical) and ARTE. Heart rate for the average of the two walking tasks was negatively related to NEAT in the overweight state while heart rate during the grade walk and average heart rate of the two tasks were negatively related to ARTE. AEE, ARTE, and NEAT were negatively related to all of the submaximal walking heart rate and VO_2 (3 mph on flat, 3 mph up grade, and average of the two walking tasks).

Discussion

Relatively high levels of AEE are important for preventing weight regain following weight loss (31; 40). Unfortunately, participation in physical activity often decreases following weight loss (24). Consistent with our hypothesis TEE, AEE, and NEAT decreased following weight loss in subjects who did not exercise train during energy restriction. On the other hand, exercise training enhanced post weight loss energy expenditure so that activity-related energy expenditure was not reduced following weight loss. In fact, both the aerobic and resistance training groups experienced non-significant increases in TEE and AEE. In addition, the resistance training group increased ARTE, a measure of free living physical activity corrected for differences in locomotion economy. High walking exercise economy and ease (low heart rate) were significantly related to both NEAT and ARTE. In addition, ease and economy of walking increased in the resistance training group following weight loss. These results support the concept that energy expenditure can be maintained and physical activity increased following weight loss if exercise training and especially resistance training occur during energy restriction.

Previous work has shown that aerobic and resistance training results in increased REE (18; 37) and TEE (10; 18) supporting the hypothesis that exercise training, especially resistance training, increases TEE by increasing REE, probably through either increased fat free mass (15) or post-exercise elevation of metabolism that lasts more than 24 hours (12; 38). In addition, exercise training increases locomotion economy and ease (4; 7; 16; 19; 28; 34; 35) and AEE (10) and NEAT (10) while others show reductions (6; 10). For example, Goran and Poehlman (6) found a decrease in AEE following an aerobic training program of 8 weeks. It is possible that the exercise stimulus may have exceeded the recovery capacity of older adults, and as such, resulted in a classic "overtraining response" in this relatively high intensity (75% of VO_2max) and short adaptation period (8 weeks) training program. Consistent with the concept that more is not always better, we found increases in NEAT of 200 kcal/day following 16 weeks of 2 days/week combined aerobic and resistance training but a decrease in NEAT of 150 kcal/day in a group that did combined aerobic and resistance training 3 days/week for 16 weeks. Since caloric restriction may offer dieters an added stress, it is not clear what effects the added stress of an exercise training program may have on NEAT. In addition, it is not clear what effect weight loss has on energy expenditure when measured in energy balance. Recently, St. Onge et al (33) reported no decrease in any energy expenditure compartment including AEE. However, the subjects lost a relatively small amount of weight (less than 6 kg and less than 7% loss for all groups) On the other hand, Leibel et al (24) report quite large losses in total, resting, and non-resting energy expenditure following a larger loss of weight (7–9 kg, 10% loss). In this study, that included even a larger decrease in body weight (12 kg and over 15% loss for all groups) a large decrease in TEE, REE, AEE and ARTE occurred in the no-exercise group. However, no decrease occurred in the two exercise groups in either TEE, AEE, or ARTE and the resistance training group actually increased NEAT. Since maintaining high AEE seems to be important for preventing weight regain following dieting (31; 40), these data strongly support the inclusion of exercise training during weight loss interventions.

The decrease in NEAT in the non-exercise group was over150 kcal/day, (~27%). Several possibilities may exist for the decrease in NEAT. First, less energy was required for locomotion following body weight reduction in the exercise groups. The minutes/day of physical activity estimate did not significantly decrease in the no exercise group (14% non-significantly lower ARTE post-exercise), whereas AEE decreased significantly over 24%. Thus, it is probable that changes in energy costs of walking contributed, at least in part, to the decreased NEAT found with the no-exercise group. On the other hand, the aerobic trainers showed a strong trend for increasing ARTE (19%) and the resistance trainers significantly increased ARTE (27%). Contrary to the strong trend for decreased walking economy (increased net VO_2) in the non-exercise group, walking economy in the aerobic group demonstrated a non-significant increase while the resistance group demonstrated a significant increase in walking economy. Coupled with the significant relationships between walking economy/ease measures with NEAT and especially ARTE, it is probable that exercise training, especially resistance training, improved exercise economy, thus enhancing ARTE and NEAT in those subjects that exercise trained.

Resting energy expenditure following a resistance training program increases primarily by increasing FFM (10; 15). Following a 15% weight loss, resistance training has been shown to slow the decrease in REE (13), whereas following less extreme weight loss of 7% resistance training appears to have little effect on REE (33). The decrease in REE was not different between groups in this study although the resistance training group did show a slight non-significant trend for a smaller decrease in REE than the other two groups. The resistance training group did not decrease FFM (+0.3 kg) and the other groups decreased FFM (aerobic group −0.5 kg and the no-exercise group −1.0 kg). It appears that resistance training may have little effect on REE following weight loss, especially when the weight losses are modest. On the other hand, continuation of resistance training after weight loss would be expected.

It might be argued that exercise training had little effect on NEAT and AEE since the final values for the 3 groups were quite similar. Subjects were randomly assigned to groups so it is surprising there are group differences in the energy expenditure measures TEE, AEE, ARTE, and PAL at baseline. The group differences seem to be primarily due to the relatively large baseline values for the no exercise group, contrasting to the relatively low values for the resistance training group. The non-significant slightly larger body weight and FFM values for the no exercise group at baseline explain a small amount of the baseline difference but not all of the difference. Multiple variables influence participation in free living physical activity, including occupation, family considerations and leisure time activities. These values were not assessed nor manipulated in this study, so we can not speculate as to why these initial differences occurred. We, however, think that it is notable that the resistance training group increased NEAT while the no exercise group decreased NEAT following weight loss. For some reason, the resistance trainers increased physical activity during their non-exercise training time, presumably due in part to the resistance training improving locomotion economy. As with our previous work, locomotion ease and economy are related to increased participation in NEAT, supporting this premise. With this said, it is should be remembered the resistance training group only showed a small non-significant difference in energy expenditure compared to the no exercise group in the final evaluation.

In conclusion, exercise training, particularly resistance training, is important for maintenance of NEAT following weight loss. This is especially apparent in the maintenance of AEE, NEAT, and ARTE, all factors that are known to be important for slowing and even preventing weight regain.

Acknowledgments

This work was supported by the NIH grants R01AG027084-01, R01 AG27084-S, P30 DK56336, P60 DK079626, UL 1RR025777.

The authors thank David Bryan, Bob Petri, and Paul Zuckerman for help in data acquisition.

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Table 1

Descriptive and fitness variables

Variable	Group	Overweight	Post overweight	Delta (Post- Overweight)	P
Age (yrs)	Aerobic	35.2±7.0			0.39
	Resistance	33.9±6.1			
	No Exercise	35.6±5.5			
Weight (kg)	Aerobic	76.9±6.7	64.4±6.1	−12.5±2.3	Time < 0.01
	Resistance	77.5±7.6	65.9±6.5	−11.6±2.3	group = 0.61
	No Exercise	78.1±6.9	65.9±6.3	−12.2±3.1	T x G = 0.19
BMI (kg/m^2)	Aerobic	28.5±1.5	23.8±1.1	−4.7±0.9	Time < 0.01
	Resistance	28.1±1.2	23.9±1.1	−4.2±0.8	Group = 0.69
	No Exercise	28.2±1.4	23.9±1.1	−4.3±1.1	T x G < 0.06
% fat	Aerobic	44.0±3.7	33.9±4.6	−10.1±2.2	Time < 0.01
	Resistance	43.0±3.6	32.4±4.5	−10.6±2.7	Group = 0.25
	No Exercise	42.7±3.4	33.5±4.7	−9.2±2.0	T x G < 0.04
Fat mass (kg)	Aerobic	33.9±5.0	22.0±4.6	−11.9±1.5	Time < 0.01
	Resistance	33.7±5.2	21.7±4.3	−12.0±2.4	Group = 0.97
	No Exercise	33.4±4.8	22.2±4.5	−11.2±2.1	T x G = 0.28
Fat free mass (kg)	Aerobic	43.0±3.7	42.5±3.5	−0.5±1.5	Time <0.01
	Resistance	44.2±4.1	44.5±3.7	+0.3±1.4	Group = 0.08
	No Exercise	44.7±3.7	43.7±4.0	−1.0±1.7	T x G < 0.01
Knee extension strength (N)	Aerobic	493±124	470±124	−23±12	Time = 0.70
	Resistance No	568±179	599±136	+31±12	Group < 0.01
	Exercise	551±167	529±176	−22±16	T x G = 0.09
Elbow flexion strength (N)	Aerobic	191±35	172±36	−19±2	Time < 0.03
	Resistance	196±32	202±37	+ 6±3	Group < 0.01
	No Exercise	202±30	195±32	− 7±3	T x G < 0.01

Variable	Group	Overweight	Post overweight	Delta (Post- Overweight)	P
VO_2max (ml/kg/min)	Aerobic	27.9±4.1	34.8±5.6	+6.9±3.0	Time < 0.01
	Resistance	29.1±3.6	33.4±4.6	+4.3±3.2	Group 0.24
	No Exercise	27.7±3.8	31.7±4.7	+4.0±2.4	T x G < 0.01
VO_2max (L/min)	Aerobic	2.02±0.30	2.13±0.31	+0.11±0.02	Time = 0.07
	Resistance	2.24±0.36	2.19±0.37	−0.05±0.02	Group = 0.16
	No Exercise	2.12±0.32	2.06±0.33	−0.06±0.02	T x G = 0.03

Table 2

Submaximal 3 mph flat walking and 2.5% grade walking economies and heart rates.

Variable	Groups	Over-weight	Post over- weight	Delta (Post – Overweight)	P
3 mph submax walk heart rate (beats/min)	Aerobic	121±14	110±17**	−11±13	Time < 0.01
	Resistance	120±13	109±15**	−11±11	Group = 0.73
	No Exercise	118±15	109±15**	− 9±11	T x G = 0.80
3 mph submax walk VO_2 (ml/kg/min)	Aerobic	12.1±1.4	11.9±1.4	−0.2±1.5	Time = 0.62
	Resistance	12.0±1.3	11.7±1.5	−0.3±1.8	Group = 0.84
	No Exercise	11.9±1.5	12.2±1.7	+0.3±1.8	T x G = 0.32
3 mph submax walk net VO_2 (ml/kg/min)	Aerobic	9.4±1.1	9.0±1.5	−0.4±1.6	Time < 0.04
	Resistance	9.4±1.2	8.8±1.4*	−0.6±1.6	Group = 0.74
	No Exercise	9.2±1.5	9.4±1.6	+0.2±1.5	T x G = 0.11
3 mph submax grade walk heart rate (beats/min)	Aerobic	137±15	124±17**	−13±12	Time < 0.01
	Resistance	135±14	122±16**	−13±11	Group = 0.78
	No Exercise	134±17	123±16**	−11±12	T x G = 0.82
3 mph submax grade walk VO_2 (ml/kg/min)	Aerobic	14.7±1.4	14.8±1.6	+0.1±1.5	Time = 0.19
	Resistance	14.6±1.6	14.6±1.5	0.0±1.9	Group = 0.71
	No Exercise	14.5±1.7	15.0±1.8	+0.5±1.9	T x G = 0.42
3 mph submax grade walk net VO_2 (ml/kg/min)	Aerobic	12.3±1.3	12.0±1.3	−0.3±1.4	Time = 0.37
	Resistance	12.2±1.3	11.6±1.4	−0.6±1.8	Group = 0.68
	No Exercise	11.9±1.6	12.2±1.6	+0.3±1.7	T x G = 0.12
Average 2 task heart rate (beats/min)	Aerobic	129±14	117±17	−12±12	Time < 0.01
	Resistance	127±13	116±15	−11±10	Group = 0.71
	No Exercise	126±16	115±15	−11±11	T x G = 0.78
Average 2 task VO_2 (ml/kg/min)	Aerobic	13.4±1.2	13.4±1.4	0.0±1.4	Time = 0.63
	Resistance	13.3±1.4	13.1±1.5	−0.2±1.8	Group = 0.80
	No Exercise	13.2±1.5	13.6±1.7	+0.4±1.7	T x G = 0.80

Variable	Groups	Over-weight	Post over- weight	Delta (Post – Overweight)	P
Average 2 task net VO_2 (ml/kg/min)	Aerobic	10.9±1.2	10.6±1.3	− 0.3±1.4	Time = 0.13
	Resistance	10.8±1.4	10.2±1.4*	−0.6±1.7	Group = 0.70
	No Exercise	10.6±1.5	10.81.8	+0.2±1.7	T x G = 0.21

Significant post hoc difference from overweight state, $p < 0.05$

Significant post hoc difference from overweight state, $p < 0.01$

Table 3

Energy expenditure and physical activity variables.

Variable	Groups	Over-weight	Post over- weight	Delta (Post- Overweight)	P
TEE (kcal/d)	Aerobic	2095±392	2032±329	− 63±404	Time <0.03
	Resistance	1905±346	1968±290	+ 63±411	Group <0.05
	No Exercise	**2194±271**	**1935±388***	−259±355	T x G <0.10
REE (kcal/d)	Aerobic	**1320±127**	**1246±127***	−74±107	Time <0.01
	Resistance	**1358±122**	**1296±128***	−62±74	Group 0.13
	No Exercise	**1386±127**	**1303±117***	−83±116	T x G 0.73
AEE (kcal/d)	Aerobic	559±301	572±291	+ 13±354	Time 0.84
	Resistance	362±303	471±212	+109±370	Group <0.02
	No Exercise	**585±223**	**443±313***	−142±326	T x G <0.02
NEAT (kcal/d)	Aerobic	559±301	472±289	− 87±354	Time 0.07
	Resistance	362±296	423±218	+ 61±372	Group 0.06
	No Exercise	**585±222**	**442±313***	−143±326	T x G 0.09
ARTE index (minutes/d)	Aerobic	136±71	162±85	+26±90	Time 0.09
	Resistance	**91±72**	**135±63***	+44±92	Group 0.05
	No Exercise	147±67	126±93	−21±97	T x G <0.05
PAL (TEE/REE)	Aerobic	1.54±0.30	1.63±0.30	+0.09±0.30	Time 0.27
	Resistance	**1.39±0.29**	**1.52±0.18***	+0.13±0.31	Group 0.04
	No Exercise	1.57±0.21	1.46±0.30	−0.06±0.29	TxG <0.01

Significant post hoc difference, $p < 0.05$

Table 4

Correlation table for overweight time point

	AEE/NEAT	ARTE
Walk heart rate	−0.163*	−0.176*
Walk VO_2	0.001	−0.065
Grade walk heart rate	−0.132	−0.141*
Grade walk VO_2	−0.012	−0.078
Avg 2 tasks heart rate	−0.150*	−0.160*
Avg 2 tasks VO_2	−0.007	−0.160*

Table 5

Correlation table for post weight loss time point

	AEE	ARTE	NEAT
Walk heart rate	−0.217*	−0.266**	−0.204*
Walk VO_2	−0.178*	−0.255**	-0.180*
Grade walk heart rate	−0.203*	−0.262**	−0.178*
Grade walk VO_2	−0.226*	−0.307**	−0.229*
Avg 2 tasks heart rate	−0.201 *	−0.258**	−0.182*
Avg 2 tasks VO2	−0.227*	−0.323**	−0.226*