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Separate and combined effects of exercise training and weight loss on exercise efficiency and substrate oxidation

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Running head:

Exercise training, weight loss and muscular efficiency

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ABSTRACT

Purpose: Perturbations in body weight have been shown to affect energy expenditure and efficiency during physical activity. The separate effects of weight loss and exercise training on exercise efficiency or the proportion of energy derived from fat oxidation during physical activity, however, are not known. The purpose of this study was to determine the separate and combined effects of exercise training and weight loss on metabolic efficiency, economy and fat oxidation during steady state moderate submaximal exercise.

Methods: 64 sedentary older (67±.5) overweight to obese (30.7±.4kg/m^2) volunteers completed four months of either diet induced weight loss (WL,n=11), exercise training (EX,n=36) or the combination of both interventions (WLEX,n=17). Energy expenditure, gross efficiency (GE), economy (EC) and proportion of energy expended from fat (EF) were determined during a one-hour submaximal (50% of VO_2peak) cycle ergometry exercise before the intervention and at the same absolute work rate after the intervention.

Results: EX increased GE by 4.7±2.2%. EC was similarly increased by 4.2±2.1% by EX. The addition of concomitant WL to EX (WLEX) resulted in greater increases in GE (9.0±3.3%) compared to WL alone but not compared to EX alone. These effects remained after adjusting for changes in LBM. The proportion of energy derived from fat during the bout of moderate exercise increased with EX and WLEX but not with WL.

Conclusion: Exercise training, either alone or in combination with weight loss, increases both exercise efficiency and the utilization of fat during moderate physical activity in previously sedentary, obese older adults. Weight loss alone, however, neither significantly improves efficiency nor utilization of fat during exercise.

KEYWORDS: Gross efficiency, exercise economy, aging

INTRODUCTION

Obesity and aging have both been associated with alterations in resting energy metabolism (10, 33). A number of studies have also examined the effects of diet-induced weight loss (23, 32), exercise (15, 35) and the combination of diet and exercise (27, 37) on energy expenditure and substrate metabolism during resting post-absorptive, post-prandial or insulin-stimulated conditions. Far fewer studies have been conducted to examine energy metabolism during physical activity in obesity (16, 19) or aging (5). In particular, the effects of weight loss or exercise training on energy metabolism *during* physical activity have not been fully elucidated.

Skeletal muscle work efficiency may be expressed as gross efficiency, net efficiency or delta efficiency. The basic definition of gross efficiency (GE) during steady state exercise is the ratio of work accomplished to the total energy expended during that specific activity and is expressed as a percentage (13). Net efficiency and delta efficiency use the change in work performed and the change in energy expanded either from baseline (13) or computed from the slope of a linear relationship between energy expended and work accomplished (8). Another common concept related to efficiency is the term of economy (EC), which is a measure of oxygen consumption per unit of work (26).

The concept of exercise efficiency may be important to consider from two very different perspectives. A higher or improved efficiency may be beneficial to sports performance in athletes. Coyle et al.(8) have shown that competitive cyclists who had a higher proportion of type 1 muscle fibers with a higher oxidative capacity were more efficient during cycling. On the other hand, and perhaps counter intuitively from a sports performance perspective, requiring less energy for activity, i.e. greater efficiency, may be a disadvantage for obesity, weight loss or maintenance of weight loss. Obese subjects have a lower efficiency than normal weight subjects for cycling (22) as well as for walking and stepping (7). During and after weight loss, skeletal muscle work efficiency is increased (34); this being even most evident at lower levels of physical activity (29, 34). However, these studies did not examine the separate effects of increased physical activity and weight loss on exercise efficiency. Therefore, the purpose of this study was to determine the separate and combined effects of weight loss and exercise training on exercise efficiency and economy in older overweight and obese subjects. Moreover, another objective was to determine the distinct and combined effects of weight loss and exercise on substrate, i.e. fat and carbohydrate utilization during the same bout of moderate exercise. We hypothesized that chronic exercise would have more of an impact on exercise efficiency and fat oxidation compared to diet induced weight loss.

METHODS

Study design and subjects

A total of 64 older (67±.5 years old) overweight or obese (30.7±.4 kg/m^2) volunteers (38 females and 26 males) were included in this study. 52 of them participated in a 3 arms randomized clinical trial consisting in a 16 weeks intervention of either diet induced weight loss (WL) or exercise training (EX) or the combination of both interventions (WLEX). 12 subjects were part of our pilot study and received without randomization the EX intervention.

None of the volunteers were engaged in regular physical exercise (>1x/week) and all were weight stable (±3 kg) for at least 6 months before the study. Subjects were excluded if they had a history of type 2 diabetes, coronary heart disease, peripheral vascular disease, uncontrolled hypertension or if they were taking chronic medications known to affect glucose homeostasis. We also excluded subjects that had among the screening testing an anemia (Hct<34%), clinical hypothyroidism (TSH>8uIU/ml) or elevated liver enzymes (25% above the reference range). The protocol was approved by the University of Pittsburgh Institutional Review Board. All volunteers gave written informed consent.

Intervention groups

Diet induced weight loss (WL): In order to achieve the goal of 10% weight loss, subjects were prescribed a caloric deficit of 500-1000 kcal/day based on recent food records combined with a low fat diet (<30% of calories from fat). Subjects met weekly with a registered dietician for individual counseling, review of food records and weight monitoring.

Exercise intervention (EX): The exercise training protocol consisted of a 16 week moderate intensity supervised aerobic exercise regimen. Subjects were asked to engage in 3 to 5 sessions per week with at least 3 sessions supervised in our facility. The intensity and duration of the exercise sessions was progressively adapted to reach 45 minutes and 75% of their peak aerobic capacity. Subjects could walk, bike or row, although walking was the primary mode of exercise. Exercise intensity was monitored by the use of heart rate (HR) monitors (Polar Electro Oy, Finland). For the first 8 weeks, the prescription was based on the subject's peak HR achieved during the baseline graded exercise test. For the second 8 weeks, the prescription was adapted from a submaximal exercise test performed at the midpoint. Exercise logs and HR monitors were also used for the unsupervised sessions.

Diet induced weight loss and Exercise (WLEX): Subjects in this group received both of the interventions described above.

Outcome measures and testing

All of the outcome measures were assessed before and after the 16 week intervention following a pre/post intervention research design. It is important to note that the two groups who underwent weight loss maintained stable weight for a period of 2 weeks prior the post-intervention measurements.

Anthropometric measures included weight and height. Weight was measured on a calibrated medical digital scale (BWB-800, Tanita Corporation, Japan) in undergarments. Height was measured at the same time with a wall-mounted stadiometer. Body mass index (BMI) was calculated as weight (kg) divided by square height (m^2).

Blood analyses performed for the screening procedure were processed through standard hospital certified laboratory protocols.

Lean Body Mass (LBM) and *Fat Mass* (FM) were assessed by dual-energy X-ray absorptiometry (Lunar, GE Lunar Prodigy and Encore 2005 software version 9.30). LBM was used to express measures and computations in relative units.

Peak aerobic capacity (VO_2 peak) was measured using a graded exercise protocol on an electronically braked cycle ergometer (Ergoline 800S, Sensormedics, Yorba Linda, CA) as described previously (31). Heart rate, blood pressure and electrocardiogram were recorded before, during and after the exercise test. Oxygen consumption was computed via indirect calorimetry (Moxus, AEI Technologies, Pittsburgh). To account for a possible learning effect, 14 subjects repeated this test at both time points; thus performing a total of four tests (two before the intervention and two after the intervention).

Percutaneous muscle biopsies were obtained by a physician from the vastus lateralis muscle after an overnight visit. The proportion of type I and type II muscle fibers were determine by the use of histochemical analysis as previously described (31).

A steady state submaximal exercise test was performed one week apart of the overnight visit. At baseline, subjects exercised on the braked cycle ergometer (Ergoline 800S, Sensormedics, Yorba Linda, CA) at 50% of their pre-determined peak aerobic capacity. After the intervention, the participants repeated the test at the same absolute work rate compared to pre-intervention. Indirect calorimetry, used to measure oxygen consumption (VO_2) and carbon dioxide production (VCO_2), was performed at 15, 30, 45, and 60 min of exercise. Cadence was maintained constant throughout the one-hour exercise bout and was similar in the pre- and post- intervention measurements. Only data from the last 3 time points (min 28-30, 43-45 and 58-60) was used to ascertain steady state levels. We did not use the first 15 minutes of data due to the fact that during the pre-intervention workload adjustments were made during that time window to match exactly 50% of the VO_2peak. Subjects were instructed to avoid strenuous physical activity for 2 days before and to eat at least 200g of carbohydrates for 3 days before the submaximal exercise test to ensure adequate glycogen stores for the exercise bout. In addition, they were asked to record food intake in a diary for the 3 days before this test so that they could replicate their diet during the 3 days preceding the post intervention test. To assess the variation in the measurement tool and a possible learning effect, a subset of individuals (n=14) performed 2 tests before and 2 tests after the intervention. For each of these time points, VO_2 at the same work was not lower in the second test compared with the first test, indicating no learning effect.

Efficiency and substrate oxidation computations

The mean values of VO_2 and VCO_2 of the last 5 data points collected at each of the 3 steady state time points from the submaximal exercise test were used to compute cycling efficiency and substrate oxidation values.

Energy expended (EE) during steady state exercise (expressed in kcal/min) was calculated adapting the formula of Brouwer (6):

$$EE_{(kcal/min)}=[[((VO_{2\ (l/min)}x3.869)+(VCO_{2(l/min)}\ x\ 1.195))x(4.186/60)x1000x4.2]/1000]\ x60$$

Gross Efficiency (GE) during steady state exercise was calculated as the ratio of the work accomplished per minute (Watts converted in kcal/min) to the EE per minute (in kcal/min)(8):

$$GE = Work_{(kcal/min)} / EE_{(kcal/min)}$$

Exercise Economy (EC) was computed as the ratio of the work accomplished per minute (Watts converted in kcal/min) by the mean oxygen consumption (l/min)(26):

$$EC_{(kcal/l)} = Work_{(kcal/min)} / VO_{2\ (l/min)}$$

Systemic carbohydrate (Cho-ox) and fat oxidation (Fat-ox) rates were calculated using the stochiometric equations of Frayn (11):

$$\text{Fat-ox}_{(mg/min)} = 1.67\ VO_2 - 1.67\ VCO_2$$

$$\text{Cho-ox}_{(mg/min)} = 4.55\ VCO_2 - 3.21\ VO_2$$

The Fat-ox value were then transformed into kcal/min and expressed as a proportion of energy derived from fat (EF):

$$EF_{(\%)} = (\text{Fat-ox}_{(kcal/min)} / EE_{(kcal/min)})*100$$

Protein oxidation rates were not included based on our prior work demonstrating that rates of urinary nitrogen excretion were similar in lean and obese subjects during resting conditions (16) and on the assumptions that the amount of proteins oxidized and other metabolic processes (such as gluconeogenesis from proteins, ketone body formation and lipogenesis) during exercise are quantitatively negligible compared to glucose and fatty acid oxidation (28).

Statistical Analysis

Data are presented in terms of mean and standard error of the mean (SEM). After exploring the data for outliers and checking the assumptions, one-way ANOVAs were performed to compare baseline characteristics between groups. When needed, post hoc tests were used with the Tukey-Kramer HSD adjustment. If the assumptions of normality (Shapiro-Wilk test) and of equal variances (Levene test) were not met, baseline comparisons between groups for these specific variables were performed using the non-parametric Kruskal Wallis test. Baseline gender differences were explored with an independent t test or the non-parametric Mann Whitney test.

Simple linear regressions were performed to look at the linear relationship between efficiency measures and BMI, VO_2peak and proportion of muscle fiber type I.

A 3x2 repeated measures ANOVA was performed on the dependent variables as a function of intervention (3 levels: WL, EX, WLEX) and time (2 levels: pre and post intervention). Pair wise comparisons using the Bonferroni adjustment for multiple comparisons were conducted (on the between and/or the within subject factors) to discriminate between means when ANOVA yielded significant results. The assumptions of compound symmetry were checked with the Box's M and the Mauchly's test. To examine the additive effect between the WL and the EX interventions, *a priori* pair wise comparisons were performed on the effects of intervention on the efficiency measures (GE and EC). The pairs [WLEX vs. WL] and [WLEX vs. EX] were compared using post hoc (pair wise comparisons on the between subject variable) within the 3x2 repeated measures ANOVA model.

A multivariate regression analysis was used to look at the predictors of the change in efficiency.

For all analyses, the alpha level was set a priori at 0.05. All statistics were performed using JMP version 5.0.1.2 and SPSS 16.0 for Mac.

RESULTS

Baseline characteristics

Baseline characteristics in the three groups are presented in Table 1. BMI was lower ($p<.05$) in the EX group compared to the WL and WLEX group. All of the submaximal exercise measures (EE, GE, EC and EF) at baseline were similar among the three groups whether the data were expressed in absolute terms (Table 1) or relative to LBM (data not shown). All of the variables were normally distributed with the exception of EE and EF. Equality of variances was assumed for all the variables, but not for LBM or EF. However, a non-parametric test (Kruskal Wallis) revealed that EE, LBM, and EF were also similar among groups.

At baseline, BMI was negatively associated with GE ($R^2 = .09$, $p=0.02$). In contrast, VO_2peak was positively associated with GE ($R^2 = .41$, $p<0.01$). Similar associations were found with GE normalized to LBM (Figure 1). The same pattern was observed between BMI and EC ($R^2 = 0.15$, $p<0.01$) and between VO_2peak and EC ($R^2 = 0.22$, $p<0.01$). No significant baseline association was found between the percentage of type I fibers and GE ($R^2 = .01$, $p=.43$) or EC ($R^2 = .01$, $p=.44$).

At baseline, men (n=26) weighed on average 11.5 kg more ($p<.001$) and had on average 16.8 kg more ($p<.001$) LBM than women (n=38). The mean BMI was similar in men and women (30.6 and 30.8 kg/m^2 respectively). Men had a higher cardiorespiratory fitness (VO_2peak) than women when expressed in absolute terms (l/min) (52.3%, $p<.001$). This difference, however, was reduced when expressed in units relative to LBM (7.8%, $p=.10$). EE during the submaximal exercise bout was 47.9% higher ($p<.001$) in men compared to women. However, this difference disappeared (3.2%, $p=0.3$) when expressed in relative units (kcal/min/kg_{LBM}). The baseline values for GE ranged from 6.8 to 19.0% with a mean of

11.5±.3%. This is somewhat lower than that reported for trained athletes (19.8±.6%)(26) but within the range reported for healthy women (11.8±.3%)(4) and men (14.3±.1%)(14). In our study, GE was 14.8% higher (p=.008) in men than women when expressed in absolute units, but women had a 23.8% greater (p=.002) GE when expressed relative to LBM. EC had a similar pattern with a higher (16.3%, p=.005) absolute economy in men compared to women, but women had a 23.1% higher (p=.002) economy than men when EC was expressed relative to LBM. The proportion of type I fibers was not significantly different between gender (49.8 ± 2.6% in women and 44.6± 3.1% in men, p=.20). Women had a higher exercise Fat-ox compared to men (16.7 vs. 13.2 umol/min/kg_{LBM}, p=.01) with a higher proportion of EF (46.7% vs. 36.1%, p=.005). Conversely, men had a higher exercise Cho-ox compared to women (89.0 vs. 69.2 umol/min/kg_{LBM}, p=.005).

Changes in physical characteristics

Changes in BMI, FM and LBM are presented in Table 2. Although all groups lost a statistically significant amount of weight, BMI and FM, the WLEX and WL groups lost significantly more weight in line with their weight loss goal (8.5±0.8 % and 9.2±1.4 % for WLEX and WL, respectively). The WL group lost more LBM than the other groups (interaction effect p<.001). None of the intervention groups had a significant change in their fiber type proportion (Table 2).

Changes in Physical Fitness and Physical Activity

The EX and WLEX groups had an increase (P<.05) in VO_2peak compared to WL (Table 2). Moreover, VO_2peak increased (P<.05) within EX and within WLEX. The same pattern was found with unadjusted means. In the EX group, subjects exercised on average 3.5±0.1 sessions/week expending 835±67 kcal/week over the course of the intervention. The WLEX group exercised on average 3.6±0.2 sessions/week expending 912±87 kcal/week.

Changes in energy expenditure during submaximal cycling exercise

Cadence was maintained constant throughout the submaximal test with an average of 61.0±0.8 revolutions per minute in the pre test and 63.0±0.8 revolutions per minute in the post testing. To achieve 50% of their VO_2peak during the submaximal test, subject's power output ranged from 20 to 75 Watts, with an average of 37.6±1.9 Watts in the pre testing. The exact same wattage was maintained during the post testing with an average of 37.6±1.9 Watts. The mean VO_2 for all subjects combined was .94±.03 l/min at baseline and .90±.03 l/min following intervention. Within each test, VO_2 was constant across the last 45 minutes of submaximal exercise. VO_2 values were also similar in two identical exercise bouts separated by one week, both before and after the intervention (N=14, $p>.05$).

Changes in EE during submaximal exercise are presented in Figure 2A. A main effect of time was found ($p<.001$). Post hoc analysis revealed that the decreased EE was only significant ($p=.004$) for the WLEX group.

Changes in gross efficiency during submaximal cycling exercise

Changes in GE during submaximal exercise are presented in Figure 2B. Significant main effects of intervention ($p=.04$) and of time ($p=.005$) were found. The EX and the WLEX group both had an increase in GE with intervention. The change in GE was not significant for the WL group. In the *a priori* pair wise comparisons, the WLEX group had a greater improvement in GE compared to the WL group (p=.02) but not to the EX group (p=.78).

Changes in exercise economy during submaximal cycling exercise

Significant main effect of intervention (p=.05) and of time (p=.007) were found. The EX and WLEX groups increased EC significantly more than the WL group. In the *a priori* pair wise comparisons, the WLEX group had a greater improvement in EC compared to the WL group (p=.03) but was not greater than the improvement with EX (p=.74).

Predictors of improved efficiency

To examine predictors of change in GE; change in weight, change in VO_2peak, change in LBM, change in FM, gender and intervention group were put into a stepwise multivariable regression. When examining all groups together, having less of a change in LBM (R^2=.19, p=.02) and an improved VO_2peak (R^2=.11, p=.008) were the only significant predictors of the improvement in GE.

Changes in fat oxidation during submaximal cycling exercise

The changes in the proportion of energy derived from fat (EF) are presented in Figure 3. A main effect of time was found (p=.04). Post hoc analysis revealed that EF increased (p=.048) within the EX group. When we combined all subjects that exercised (EX and WLEX), we also found a significant improvement in EF with intervention (p=.04). The WL group did not have an increase in fat oxidation.

DISCUSSION

The effects of body weight changes and physical activity on exercise efficiency has received relatively little attention. In particular, the separate or distinct effects of intentional, energy restriction-induced weight loss and exercise training have not until now been examined. The key findings of this study were that exercise training with or without weight loss increased exercise efficiency and the amount of energy derived from fat during a bout of moderate exercise. However, weight loss itself does not appear to significantly enhance either exercise efficiency or fat oxidation during exercise in older overweight to obese men and women.

These increases in exercise efficiency and economy are consistent with previous work by Rosenbaum and colleagues (34) who found that a program of combined weight loss and increased physical activity enhanced efficiency at very low levels of muscular work in overweight subjects. The current study builds upon this previous observation by delineating the separate effects of exercise and weight loss. The increase in efficiency specifically due to exercise training in these overweight to obese older subjects is consistent with previous studies conducted in younger normal weight subjects (14,18). Moreover, our findings indicate that at least part of the decreased efficiency that may occur with age (38) is explained by age-associated decreases in physical activity. This is in accord with earlier studies suggesting that exercise efficiency and economy may not change with advancing age in well-trained older subjects (1,3,36), or that lower exercise efficiency was reversed in older subjects following training (30).

The changes in exercise efficiency and oxygen uptake following exercise training could be influenced by both peripheral and central effects. Exercise training, but not weight loss, increased the physical fitness (VO_2peak). We did not detect significant changes in fiber type with exercise in the current study, which is in apparent contrast to two of our previous studies in similar subjects (9,31). However, this could be explained by the more rigorous three-group analysis in this study, particularly given that the magnitude of these changes were similar across these three studies. The possibility remains that alterations in energetics within muscle, including the proportion of type I muscle fibers, may play a role in altered efficiency. At the cellular level, we have shown that with a similar exercise intervention and subject population, mitochondrial activity and density was greatly enhanced by exercise (25). The increased efficiency in the current study was related to the improvement in physical fitness, but not to the increase in the proportion of type I muscle fibers. Moreover, we did not observe an association between efficiency and fiber type at baseline. Rosenbaum et al. (34) found that the increases in efficiency were paralleled by increases in the capacity for oxidative phosphorylation determined by NMR spectroscopy. In addition, in young highly trained cyclists, a higher percentage of type I muscle fibers has been associated with higher efficiency (8). Thus the possibility remains that muscle fiber type, mitochondria activity or oxidative capacity can account for efficiency at higher levels of work. It is also possible that changes in other characteristics within skeletal muscle, for example, capillarization or muscle blood flow, may contribute to the increased efficiency with exercise training. This requires further investigation.

Energy restriction-induced weight loss without an increase in physical activity in our study did not significantly increase efficiency. Moreover, the effects of weight loss and exercise were not additive. Body mass has been suggested to be an important factor in relation to efficiency (4). The changes in efficiency with weight loss could be attributed to the work of the moving legs (2) and the extra weight carried in the legs (20). While these factors might explain the weight loss effects on improved efficiency, it is highly unlikely that they accounted for the changes in efficiency observed following exercise training since this intervention did not promote substantial weight loss.

An increase in efficiency may have significant implications for older men and women who are at greater risk for the development of functional limitations. An increased efficiency during moderate levels of physical activity examined in this study would imply that activities of daily living would require less energy. This could be clinically relevant for older men and women who typically have low capacity for physical work, that is, they would require proportionately less energy of their maximal functional capacity. Another perspective is that a decrease in energy required for physical activity (increased efficiency) may theoretically hinder efforts to lose weight or to maintain weight loss in obesity. In our study, the mean increase in efficiency due to the combination of weight loss and exercise would correspond to a decrease of 0.4 kcal/min expended during the one hour of moderate exercise. At three hours of exercise per week, this increased efficiency in our subjects would require them expend an additional 67 kcal/week, or approximately 16 additional minutes of weekly leisure walking. Therefore, this should not be a practical concern.

Another key finding was that exercise training increased the relative reliance on fat oxidation during a moderate intensity bout of exercise. This response was observed in subjects who exercised with or without parallel weight loss, but not with weight loss alone. These data indicate that older-aged, overweight to moderately obese men and women can increase their reliance on fat with just moderate increases in physical activity. This is in agreement with our previous study in a similar group of subjects who had an increased fat oxidation during submaximal exercise in conjunction with an increase in the proportion of type I muscle fibers (31). These observations are supported by several previous studies demonstrating an increase in fat oxidation due to exercise training (12, 24) but not weight loss (17, 21). It is not clear whether the mechanisms responsible for the shift in substrate oxidation during a bout of physical activity also underlie the increased efficiency. Nevertheless, this study provides novel evidence that exercise training, but not energy restriction-induced weight loss, increases *in vivo* fatty acid oxidation *during* exercise.

Our study was not without limitations. We did not use efficiency measures taking into account resting values (net efficiency). Although we performed a test-retest paradigm to exclude a possible learning effect and test the variability in the measurements, we did not have a true control group to control for the variability in the tests. To exclude the confounding effect of a cardiovascular drift, we plotted heart rate and VO_2 along time; neither HR nor VO_2 increased during the submaximal exercise test. Measuring muscular efficiency during cycle ergometry may not apply to typical activities of daily living such as walking. This is especially true in situations where individuals alter their gait, i.e. specific morphotypes of obesity. Thus these results may not be generalized to all forms of exercise. In addition, we cannot discount the possibility that improvements in efficiency occurred due to biomechanical changes in movement. However, this is far less likely to occur during cycling, particularly since walking was the primary mode of exercise during training. We were also careful to account for any potential learning effect and did not observe a gender effect in the responses to intervention.

In summary, moderate increases in physical activity levels, either with or without concomitant weight loss, enhanced exercise efficiency in previously sedentary, overweight to obese men and women. In contrast, weight loss alone did not significantly enhance efficiency in these subjects. Moreover, exercise training, but not weight loss, increased the reliance on fatty acids during moderate exercise. Further research needs to be performed to determine whether or not these changes in energy metabolism due to exercise or weight loss play a role in modulating cardiometabolic risk or improving functional performance in old age or obesity.

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DISCLOSURES

Conflict of interest: The authors have nothing to disclose.

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LIST OF FIGURES AND LEGENDS

Figure 1. Simple linear correlations at baseline between gross efficiency, BMI and VO_2peak.

A. Correlation between gross efficiency normalized to lean body mass and BMI

B. Correlation between gross efficiency and VO_2peak normalized to lean body mass

Notes:

Gross efficiency (GE), Body Mass Index (BMI), Lean Body Mass (LBM)

Figure 2. Changes in energy expenditure and gross efficiency during submaximal exercise

A. Percent change in energy expenditure

B. Percent change in gross efficiency

Notes:

Groups: WL (open bar), EX (grey bar), WLEX (black bar)

Data presented as mean change (error bars are SEM)

A, B and C are significantly different (repeated measures ANOVA)

* P<.05 pre-post comparison (within subject post hoc test)

Figure 3. Changes in fat oxidation during submaximal exercise

Notes:

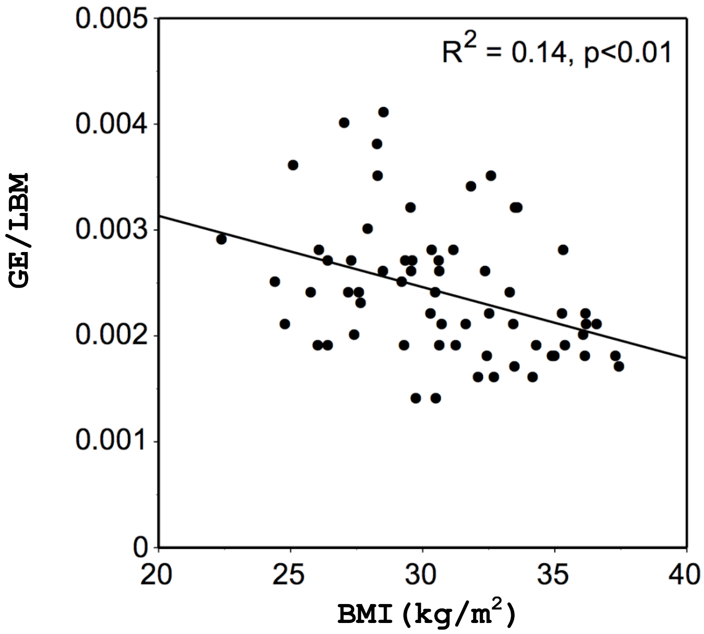
Groups: WL (open bar), EX (grey bar), WLEX (black bar)

Data presented as mean change (error bars are SEM)

* P<.05 pre-post comparison (within subject post hoc test)

Figure 1. Simple linear correlations at baseline between gross efficiency measures, BMI, and VO_2peak.

A. Correlation between gross efficiency normalized to lean body mass and BMI



B. Correlation between gross efficiency and VO_2peak normalized to lean body mass

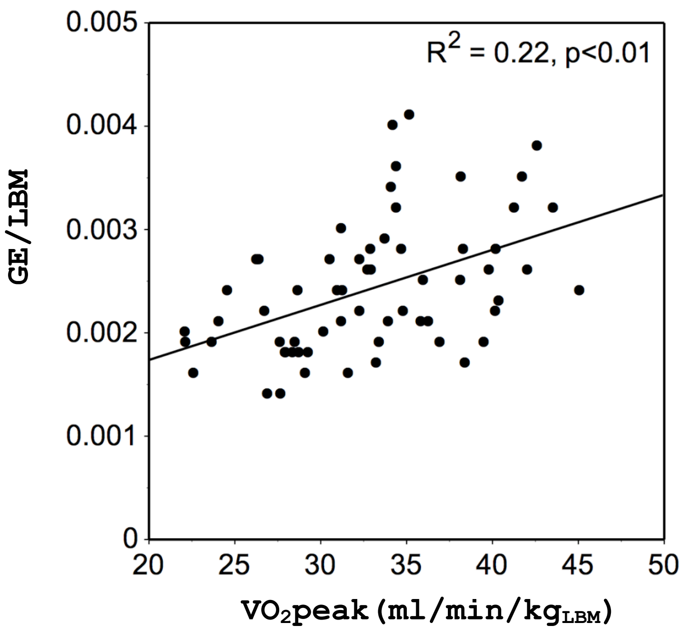


TABLE 1
Baseline Characteristics

	WL	EX	WLEX
N	11	36	17
Gender (M/F)	5/6	13/23	8/9
Age (years)	68.2 ± 1.5	67.0 ± 0.6	66.2 ± 0.9
BMI (kg/m^2)	31.6 ± 1.0[A]	29.7 ± 0.6[B]	32.2 ± 0.8[A]
LBM (kg)	47.3 ± 2.5	47.8 ± 1.5	51.6 ± 2.9
FM (kg)	38.4 ± 2.0[A]	31.4 ± 1.5[B]	36.3 ± 1.9[A]
BF (%)	43.6 ± 1.8	38.4 ± 1.6	40.3 ± 1.8
Type I Fibers (%)	51.9 ± 3.9	44.2 ± 3.1	50.7 ± 2.9
VO_{2peak} (ml/kg$_{LBM}$/min)	29.3 ± 1.6	33.5 ± 1.0	33.3 ± 1.2
EE (Kcal/min)	4.2 ± .28	4.6 ± .21	5.0 ± .33
GE	.10 ± .01	.12 ± .01	.12 ± .00
EC (Kcal/l)	.49 ± .03	.58 ± .02	.58 ± .02
EF (%)	38.4 ± 2.0	44.2 ± 2.5	41.1 ± 4.6

Notes:
Data presented as mean±SEM. Body mass index (BMI), lean body mass (LBM), fat mass (FM), percent body fat (BF), peak oxygen uptake (VO_{2Peak}), energy expenditure during submaximal exercise (EE), gross efficiency (GE), economy (EC), proportion of energy derived from fat (EF). [A] significantly different than [B] (one-way ANOVA).

TABLE 2

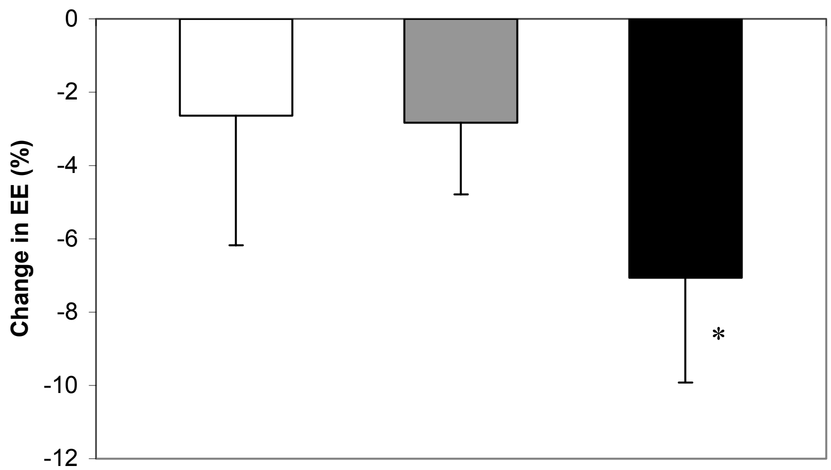
Changes in body composition and VO_2peak with intervention

	WL	EX	WLEX
BMI (%)	$- 9.3 \pm 1.4^{B*}$	$-1.3 \pm 0.4^{A*}$	$-8.6 \pm 0.8^{B*}$
FM (%)	$-16.4 \pm 2.6^{B*}$	$- 3.6 \pm 1.1^{A*}$	$-18.7 \pm 2.1^{B*}$
LBM (%)	$- 4.3 \pm 1.2^{C*}$	$.1 \pm 0.4^{A}$	$-1.5 \pm 0.5^{B*}$
Type I fibers (%)	$- 1.2 \pm 8.7$	16.7 ± 8.1	-1.6 ± 7.1
VO_2peak (%)	0.4 ± 4.5^{B}	$10.4 \pm 2.1^{A*}$	$4.3 \pm 3.2^{A*}$

Notes:
Data presented as mean percent change from baseline ± SEM. Body mass index (BMI), fat mass (FM), lean body mass (LBM), proportion of type I fibers (Type I fibers), peak oxygen uptake (VO_{2Peak}). $^{A, B}$ and ^{C} significantly different (repeated measures ANOVA). * P<.05 pre-post comparisons (within subject post hoc test).

Figure 2. Changes in energy expenditure and gross efficiency during submaximal exercise

A. Percent change in energy expenditure



B. Percent change in gross efficiency

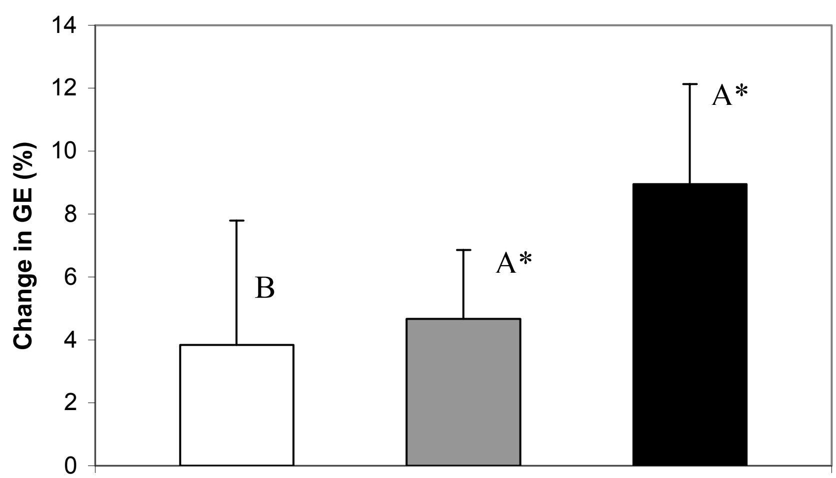


Figure 3. Changes in fat oxidation during submaximal exercise