The Independent and Combined Effects of 16 Weeks of Vigorous Exercise and Energy Restriction on Body Mass and Composition in Free-Living Overweight Men—A Randomized Controlled Trial

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This study assessed the effects of 16 weeks of energy restriction and vigorous exercise on body mass and body composition. Sixty sedentary men, mean body mass (mean ± SD) 96.3 (13.9) kg and mean age 42.4 (5.0) years, were randomly assigned to either continue their normal energy intake or restrict energy intake by 4,186 to 6,279 kJ · d^{-1}. Each group was further randomized to a control light exercise program, or a vigorous exercise program for 3 half-hour sessions per week. Vigorous exercise improved maximum oxygen consumption ($\dot{V}O_{2max}$) by approximately 24% (0.56 [95% confidence interval, 0.47 to 0.65) L · min^{-1}, *P* < .001) with no significant changes in body mass, body composition, or fat distribution. With energy restriction there was a significant reduction in body mass of 10.1 (8.0 to 12.2) kg, lean body mass (LBM) of 2.4 (1.5 to 3.3) kg, fat mass (FM) of 7.7 (5.9 to 9.6) kg, waist to hip ratio (WHR) of 0.03 (0.01 to 0.04), and the sum of 6 skinfolds of 26.9 (15.4 to 38.4) mm (*P* < .001). Combining vigorous exercise with energy restriction resulted in no further changes in measures of body composition. We conclude that in sedentary free-living overweight men, 16 weeks of energy restriction, but not vigorous intensity exercise, results in substantial reductions in body mass, LBM, and FM. Furthermore, vigorous intensity exercise when combined with energy restriction did not modify or enhance the changes in body fat distribution or body composition seen with energy restriction alone. The independent effects of exercise to induce changes in body mass and composition in the longer term in free-living overweight subjects on an energy-restricted diet deserve further study.

EXERCISE is one of the few consistent factors associated with long-term maintenance of body weight.[1] Exercise training is often recommended for use in weight loss programs either alone or in addition to energy restriction.[2] However, the role of exercise in weight reduction programs is controversial. Reviews of controlled studies have reported modest weight loss with exercise of around 2 to 3 kg[3,4] or 1 to 2 kg.[5] A meta-analysis reporting the results from 13 groups of sedentary men and 14 groups of exercising men also concluded that aerobic exercise without dietary restriction can result in modest weight loss.[6] Katzel et al[7] reported that after a 9-month intervention, energy restriction reduced body mass by 9 kg, while exercise had no significant effect despite a 17% increase in fitness. In contrast, Ross et al[8] demonstrated that 3 months of 60 minutes of daily exercise resulted in similar reductions in body weight and abdominal obesity but a greater fat loss than the diet-induced weight loss group. They further demonstrated that exercise without weight loss reduced abdominal fat.

The question of whether aerobic exercise in combination with a weight loss diet will augment the weight loss seen with diet alone is still unresolved. When endurance training has been combined with a weight loss diet, no additional benefits in body mass and body composition have been observed above those gained by dietary-induced weight loss.[9,10] Wing[5] reported that out of 13 studies reviewed for a meta-analysis, only 2 showed significant differences in weight loss between the diet and diet plus exercise condition. Another meta-analysis with a larger number of studies concluded that the weight loss achieved from diet only and diet and exercise regimens were similar.[11]

In addition to the direct energy expenditure of the activity itself, exercise has the potential for other positive benefits in weight control such as the preservation of lean body mass (LBM)[12] and an increase in resting energy expenditure.[13] Studies using moderate energy restriction (ie, a reduction of 2,093 kJ · d^{-1}) result not only in a loss of total body mass and fat, but also LBM.[14] Further, generally diets that show more than 1 kg weight loss per week have been found to do so at the expense of LBM.[15] There is some evidence that concomitant aerobic exercise training will preserve or at least minimize the loss of LBM.[12,16] However, Wilmore,[3] in his overview, reported that LBM decreased in 17 studies, and some subsequent reports have also failed to support the view that concomitant exercise will spare LBM.[17,18] In contrast, meta-analysis results have provided supportive evidence that exercise training reduces the amount of body mass lost as LBM during energy restriction–induced weight loss.[6,19]

In one of these meta-analyses,[6] it was noted that there have been no reports to date of a randomized controlled study on the effects of exercise alone on body mass and body composition in obese subjects. This review demonstrated that a change in body mass and composition was affected by the nature of the low-energy diet and concluded that it was necessary to compare individuals on the same diet while sedentary and exercising. The current study took advantage of an intervention trial on the effects of energy restriction and vigorous exercise on the clinic and ambulatory blood pressure of free-living sedentary obese men[20] to assess the independent and combined effects on body

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Submitted May 10, 2002; accepted August 8, 2002.
Supported by the National Heart Foundation of Australia, the National Health and Medical Research Council of Australia, and the Royal Perth Medical Research Foundation.
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0026-0495/03/5201-0018$35.00/0
doi:10.1053/meta.2003.50017

mass, body composition, and fat distribution restriction. The novel aspects of our report are, first, that the design of our study addresses the need to evaluate individuals on the same diet while undertaking exercise or in a control exercise condition; second, few previous studies have simultaneously evaluated changes in all 3 components of body mass, body composition, and body fat distribution with energy restriction and vigorous exercise.

MATERIALS AND METHODS

Subjects

Nonsmoking, overweight sedentary men aged 20 to 50 years were recruited in response to media advertisements. Of the 500 who responded, 260 met the initial entry criteria of between 120% and 160% ideal body mass for height, a body mass index (BMI) of greater than 25 $kg \cdot m^{-2}$, alcohol consumption less than 210 $mL \cdot wk^{-1}$, and in otherwise good health with no chronic musculoskeletal injury that would preclude exercise. Sedentary was defined as less than 2 half-hour sessions of vigorous exercise per week for the past 6 months. Subjects reported no substantial weight loss ($>$10 kg) in the preceding 12 months.

As this study was part of a parent study investigating the blood pressure responses to energy restriction and vigorous exercise,[20] subjects were further screened on the basis of an entry blood pressure in the range of 130 to 160 mm Hg systolic or 80 to 110 mm Hg diastolic. There were 60 subjects who met all entry criteria. The study was approved by the Human Rights Committee of The University of Western Australia.

Study Design

During a 2-week baseline period, assessments of fitness, body mass, body composition, anthropometric measurements, and resting energy expenditure were made and a questionnaire on several aspects of health and lifestyle was completed.

Subjects were then randomly assigned to 1 of 4 groups in a 16-week study of 2-way factorial design. Two groups were asked to continue their normal dietary habits, while subjects in the other 2 groups were given an individually tailored program that aimed to reduce their total energy intake by 4,186 to 6,279 kJ per day, with 30% derived from fat, 15% from protein, and 55% from carbohydrate. Subjects in these groups had a weight loss target of 7 to 9 kg. Within each of these 2 dietary arms, subjects were further allocated to a control light exercise group or a vigorous intensity exercise group for 3 half-hour sessions per week. The light exercise protocol consisted of a series of slow flexibility exercises once per week and stationary cycling (against zero resistance) (Monark ergometer, Varberg, Sweden) twice a week. Every second week, one cycling session was substituted with a slow walk, at a rate of approximately 2 kilometers or less in 30 minutes. This range of exercises was offered to provide variety and assist with compliance for the 16-week period. The vigorous exercise program was confined to stationary cycling 3 times per week, with subjects cycling for 30 minutes at 60% to 70% of their maximum workload, as determined from their baseline fitness assessment. All sessions included a 5-minute warm-up and cool-down and were supervised by a trained exercise supervisor.

Measurements

Physical fitness assessment. Physical fitness was assessed from a progressive multistage exercise test on an electronically braked cycle ergometer (Siemans-Elema AB, Medicinsk Teknik, Solna, Sweden) commencing at zero workload and increasing 20 W every minute with a pedal rate of 60 rpm until the subject reached volitional fatigue. Maximum workload (W_{max}) was determined as the maximum achieved for a completed minute. Oxygen consumption was measured throughout the test and recorded each minute with maximum oxygen consumption ($\dot{V}O_{2max}$) taken as the maximum minute value with a respiratory gas exchange ratio of 1.12 or when oxygen consumption had reached a plateau. Inspired volume was measured with a Morgan ventilation monitor (PK Morgan, Chatham Kent England), expired oxygen by an Applied Electrochemistry S-3A oxygen analyzer (Ametek Thermox Instrument Division, Pittsburgh, PA) and expired carbon dioxide by a Datex CD-101 carbon dioxide analyzer (Datex Instrument DY, Helsinki, Finland). Heart rate was determined for the last 15 seconds of each minute using a Cardiofax ECG-6511 (Nihon Konden, Tokyo, Japan). This fitness assessment was repeated at the end of the study between 48 and 72 hours after the last exercise session.

Body composition. Height was measured with a fixed stadiometer. Body mass was measured (to the nearest 0.01 kg) on electronic balance scales (August Sauter, Ebingen, West Germany). Body density was determined by the underwater weighing method,[21] with residual volume (RV) estimated by the nitrogen dilution technique.[22] RV was determined 3 times for each subject. The first measure was considered as a practice trial to allow for any learning effect. The mean of the second and third measures was taken as the RV if both measurements were within 100 mL of each other, otherwise RV was the mean of all 3 measurements. Subjects were weighed underwater, with 10 trials completed for each subject. All measurements were recorded and the mean of the last three measurements was used as the underwater weight.[23]

The percentage of body fat was derived using the Siri equation.[24] Fat mass (FM) was calculated by multiplying the percent fat by body mass and the LBM by subtracting FM from total body mass.[25] The mean percent coefficient of variation (CV%) for FM was 4.81% and 0.54% for LBM.

Anthropometric measurements. Skinfold thickness measurements were made at 7 standard sites (biceps, triceps, subscapular, supraspinale, abdominal, front thigh, and medial calf).[26] All sites were located and marked with measurements made on the right hand side of the body while standing except for the thigh, which was measured sitting. A John Bull caliper (British Indicators, West Sussex, England) was used to measure skinfold thicknesses to the nearest 0.2 mm and the median of three measurements used as the skinfold thickness at each site. Skinfold central adiposity was determined by taking the sum of the subscapular, supraspinale, and abdominal skinfolds, and skinfold regional adiposity from the sum of the biceps, triceps, front thigh, and medial calf skinfolds. Girths were measured to the nearest 0.1 cm, using a 5-mm flexible retractable steel tape measure (Rabone, Chesterman, England) at 7 sites: upper arm, forearm, mid thigh, calf, chest, waist, and hip. The mean technical error of measurement (TEM) for skinfolds was 2.2% and for girths, 0.7%. Central adiposity was also measured using the waist to hip ratio (WHR), which was calculated as the waist girth divided by the hip girth.

Dietary Compliance

In the run-in period all subjects were given written information and instructed how to keep accurate food records by a dietitian, with food weight and volume measured where possible. The same dietitian monitored dietary intake throughout the study with subjects completing a 3-day diet record every 2 weeks, which was individually checked by interview for clarity and reliability. Subjects randomized to energy restriction received advice on reducing their daily energy intake and changing to the target diet composition. Subjects were asked to substitute low-fat alternatives for typical high-fat foods and polyunsaturated fat for saturated fat, and to increase fruit and vegetable consumption and substitute complex carbohydrates such as wholegrain bread and cereals for refined carbohydrates. Participants were encouraged to aim for a target weight loss and to adopt the program as a lifestyle change rather than aiming for any quick weight loss. Behavior modification techniques were enlisted and the involvement of spouses and family encouraged to help compliance as the changes to diet usually needed the cooperation of the food preparer in each household. Further compliance was achieved by the plotting of 2-week progress on individual charts. Subjects assigned to the control diet group also completed 3-day diet records and were seen every 2 weeks by the dietitian to determine whether there had been any alterations in their usual eating habits. Adherence to "no dietary change" was reinforced at each visit and these participants were offered an individual weight loss program at the end of the study.

Subjects were asked to maintain their usual alcohol drinking habits throughout the study. Seven-day retrospective alcohol diaries were completed during the run-in period and at 2-week intervals during intervention to monitor any changes.

Exercise Compliance

Subjects were requested not to change their physical activity levels at work, home, or leisure and were interviewed weekly about their physical activity level. Any change in activity other than the prescribed exercise was reported in a 7-day retrospective diary with details of exercise type, intensity, and duration.

During both the light and vigorous exercise sessions, heart rate was monitored to ensure that the light intensity group did not attain heart rates that would facilitate an improvement in fitness. The vigorous group worked within a range that would improve fitness but was not so intense as to cause distress. The exercise supervisor measured heart rate with a stethoscope after 5, 20, 35, and 40 minutes of exercise. The training heart rate was determined from the mean of the heart rate at 20 and 35 minutes of exercise (ie, halfway through the session and 15 seconds before the end of the workload). The mean training heart rate was determined from the mean of all 48 sessions.

Statistical Analysis

A 2-way analysis of variance (ANOVA) model with interaction was used to compare the changes in body mass, FM, LBM, and all anthropometric measurements. To account for the differences in mass between the normal- and low-energy group at baseline, an ANOVA was repeated with the final body mass as the dependent variable and the baseline body mass as the covariate. Within group comparisons were made using a *t* test with correction for multiple means (Bonferroni's method). One-way ANOVA and chi-squared tests were used to test for any between group differences in baseline characteristics. Pearson product moment correlation coefficients were used to determine relationships between variables. It was calculated a posteriori that the study had 80% power at $\alpha = 0.05$ to detect an energy restriction or exercise main effect on body mass of 5.5 kg. Baseline values are reported as the mean (±SD) and other results are expressed as mean with 95% confidence intervals in parentheses.

RESULTS

Subject Adherence and Exclusions

Fifty-one subjects completed the study and all of these completed all 48 of the prescribed exercise sessions. Eight subjects dropped out due to work commitments or a change in employment, and one because of an injury to the Achilles tendon. Body composition results are reported for 49 of the 51 subjects as 2 subjects were not able to complete underwater testing.

Baseline Characteristics

Baseline characteristics for body mass and body composition for the four study groups are listed in Table 1. All subjects were Caucasian, with a mean age of 42.4 (5.0) years. Subjects were screened on the basis of being sedentary and the mean baseline $\dot{V}O_{2max}$ of 26.9 (3.5) $mL \cdot kg^{-1} \cdot min^{-1}$ [or 2.59 (0.39) $L \cdot min^{-1}$] (Table 2) was at the lower end of the range of oxygen consumption for men aged 26 to 35 years.[27] Mean baseline daily energy intake was 9,931 (2,930) kJ.

Mean body mass was 96.3 (13.9) kg. Mean BMI was 31.1 (3.9) $kg \cdot m^{-2}$ with 55% of subjects having a BMI in excess of 30. The difference in BMI when all 4 groups were compared (Table 1) was of borderline significance ($P = .055$) with subjects in the low caloric, vigorous exercise group having the highest mean BMI. Mean FM was 24.8 (9.4) kg with a percent body fat of 24.9% (6.6%). LBM was 72.0 (6.8) kg and subjects had a mean body density of 1.04 (0.01) $g \cdot mL^{-1}$.

The mean sum of 6 skinfolds was 155.7 (37.8) mm or 151.4 (36.0) mm if corrected for height.[21] The mean sum of central skinfolds was 95.7 (22.3) mm and sum of regional skinfolds was 71.5 (23.7) mm. The group allocated to low energy and

Table 1. Baseline Characteristics of Subjects in Each of the Four Study Groups

	Normal Energy		Low Energy	
	Light Exercise (n = 17)	Vigorous Exercise (n = 13)	Light Exercise (n = 14)	Vigorous Exercise (n = 15)
Height (cm)	175.7 ± 5.6	174.3 ± 5.8	177.7 ± 5.4	175.5 ± 4.8
Body mass (kg)	91.9 ± 11.8	92.6 ± 13.9	97.7 ± 15.7	102.8 ± 12.9
FM (kg)	21.2 ± 7.2	24.1 ± 9.5	24.5 ± 9.7	29.0 ± 10.2
LBM (kg)	70.7 ± 6.1	69.2 ± 6.9	73.2 ± 8.2	73.7 ± 6.1
BMI ($kg \cdot m^{-2}$)	29.7 ± 3.4	30.5 ± 3.9	30.9 ± 4.3	33.3 ± 3.6*
Sum 6 skinfolds (mm)	139.7 ± 30.7	162.7 ± 35.3	149.8 ± 37.3	171.3 ± 42.4
Sum central skinfolds (mm)	90.1 ± 22.9	98.5 ± 20.3	91.02 ± 21.2	103.5 ± 23.4
Sum regional skinfolds (mm)	54.5 ± 16.4	73.9 ± 20.6	73.4 ± 25.3	80.7 ± 26.9*
WHR	0.99 ± 0.03	0.99 ± 0.06	0.99 ± 0.04	1.02 ± 0.04

NOTE. Values are mean ± SD.

There was a significant difference between the low energy and vigorous exercise group and the other 3 groups at baseline for BMI and the sum of regional skinfolds. *$P < .05$ (1-way ANOVA).

Table 2. Fitness, Energy Intake, and Percentage of Energy Derived From Carbohydrate, Fat, and Protein for Subjects in Each of the Four Study Groups Before and After the 16-Week Intervention

	Normal Energy		Low Energy	
	Light Exercise (n = 17)	Vigorous Exercise (n = 13)	Light Exercise (n = 14)	Vigorous Exercise (n = 15)
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)				
Pre	2.43 (2.23-2.60)	2.58 (2.39-2.76)	2.62 (2.39-2.85)	2.74 (2.52-2.97)
Post	2.58 (2.35-2.82)*	3.13 (2.95-3.32)‡	2.64 (2.43-2.85)	3.38 (3.08-3.68)‡
Energy intake ($kJ \cdot d^{-1}$)				
Pre	9,646.5 (7,770.6-11,526.3)	9,117.3 (7,586.2-10,648.4)	10,194.0 (8,762.5-11,625.5)	10,712.4 (9,176.7-12,268.1)
Post	9,280 (8,182.2-10,377.8)	9,712.3 (7,824.8-11,599.8)	6,170 (5,218-7,122.5)‡	5877.7 (4,940.4-6,815.0)†
Carbohydrate (%)				
Pre	41.7 (37.8-45.6)	41.3 (36.9-45.7)	39.7 (36.3-42.3)	41.3 (37.5-45.0)
Post	44.7 (42.0-47.4)	40.3 (35.3-45.4)	45.5 (42.9-48.2)†	45.2 (39.8-50.7)*
Fat (%)				
Pre	35.1 (29.9-40.2)	35.7 (32.1-39.2)	37.8 (33.9-41.7)	37.2 (33.9-40.6)
Post	33.6 (30.3-36.9)	35.8 (31.6-40.0)	22.2 (18.2-26.1)‡	21.6 (16.9-26.3)‡
Protein (%)				
Pre	17.9 (15.4-20.2)	17.8 (15.9-19.7)	17.8 (16.2-19.5)	17.2 (15.5-18.9)
Post	19.7 (17.2-22.2)	17.6 (15.0-20.1)	26.1 (23.2-28.9)‡	25.1 (22.1-28.1)‡

NOTE. Values are mean with 95% confidence intervals in parentheses.

There were no significant differences between groups at baseline. Within-group changes from baseline, significance of a Bonferroni *t* test: *$P < .05$, †$P < .01$, ‡$P < .001$.

vigorous exercise had significantly higher biceps skinfold ($P < .05$) (Table 3) than the normal energy light exercise group.

Mean baseline waist and hip girth measurements were similar [106.8 (9.8) cm and 106.7 (6.9) cm, respectively], resulting in a mean WHR of 1.0 (0.04). All subjects had WHR in excess of 0.90, which is considered the threshold for increased risk of coronary artery disease.[28] Twenty-eight subjects (47%) had values in excess of 1, indicating a high prevalence of abdominal adiposity. There was no significant difference between groups in WHR at baseline, but chest, waist, thigh, and calf girths were significantly higher ($P < .05$) for the energy restriction and vigorous exercise group.

Table 3. Skinfold Measurements of Subjects in Each of the Four Study Groups Before and After the 16-Week Intervention

	Normal Energy		Low Energy	
	Light Exercise (n = 17)	Vigorous Exercise (n = 13)	Light Exercise (n = 14)	Vigorous Exercise (n = 15)
Biceps (mm)				
Pre	8.9 (7.2-10.3)	11.0 (8.2-13.8)	10.6 (8.1-13.1)	12.5 (10.7-14.2)*
Post	9.2 (7.2-11.3)	10.1 (7.6-12.6)	8.6 (5.6-11.6)§	9.4 (7.3-11.5)§
Tricep (mm)				
Pre	16.7 (14.5-18.9)	18.1 (14.8-21.4)	18.7 (15.4-21.9)	20.7 (16.2-25.3)
Post	16.4 (13.7-19.1)	17.3 (13.1-19.1)	13.0 (11.5-14.5)§	16.7 (12.8-20.5)‡
Subscapular (mm)				
Pre	25.8 (20.9-30.7)	29.5 (23.6-35.4)	28.1 (23.2-33.0)	32.8 (28.4-37.1)
Post	27.4 (20.8-33.9)	27.9 (20.4-35.5)	23.1 (18.0-28.2)‡	26.8 (21.4-32.3)‡
Supraspinale (mm)				
Pre	27.2 (22.7-31.8)	30.7 (25.9-35.4)	29.2 (24.9-33.6)	32.3 (27.4-37.2)
Post	24.4 (19.3-29.5)	28.8 (22.5-34.9)	20.5 (16.8-24.3)§	23.4 (18.1-28.7)§
Abdomen (mm)				
Pre	37.1 (31.9-42.3)	38.3 (33.7-42.9)	33.7 (27.5-39.9)	38.4 (32.8-44.1)
Post	32.7 (26.4-38.8)	39.2 (34.7-43.7)	28.1 (23.2-33.3)§	31.5 (25.5-37.4)§
Calf (mm)				
Pre	12.2 (10.4-14.1)	17.3 (12.5-22.2)	18.6 (13.1-24.4)	18.4 (15.0-21.8)
Post	13.5 (10.4-16.5)	15.2 (12.3-18.1)	12.9 (10.8-14.9)§	15.4 (11.6-19.2)†
Thigh (mm)				
Pre	20.8 (16.2-25.4)	29.0 (24.1-33.9)	25.4 (19.7-31.2)	29.1 (22.9-35.4)
Post	21.8 (16.5-26.9)	25.0 (18.4-31.6)	19.0 (14.6-23.4)‡	23.9 (16.4-31.4)†

NOTE. Values are mean with 95% confidence intervals in parentheses.

There was a significant difference between the normal energy light exercise and the low energy vigorous exercise groups at baseline for bicep skinfold: *$P < .05$ (1-way ANOVA). Within-group differences from baseline, significance of a Bonferroni *t* test: †$P < .05$, ‡$P < .01$, §$P < .001$.

Exercise Training Intensity

The vigorous intensity group exercised at a mean workload of 60% maximum (range, 54% to 68%). Some subjects could not tolerate an initial workload of 60% W_{max} and commenced at about 50% W_{max}, increasing to 60% as fitness improved. The mean training intensity for the vigorous intensity group was 76% of heart rate reserve (HR_{res}) and 18% HR_{res} in the light intensity group. If the light intensity group is analyzed according to separate modes of exercise, cycling was performed at a mean intensity of 17% HR_{res}, flexibility exercises at 19%, and walking at 23%. There was a significant difference ($P < .05$) in intensity between walking and the other 2 modes of exercise, but the walk was completed only 6 times over the 16 weeks. When 7-day retrospective diaries were analyzed, there was no evidence of any significant extramural exercise in any group.

Fitness

There was a 24% improvement in oxygen consumption with vigorous intensity exercise ($F_{1,47} = 111.3$, $P < .001$), from 2.67 (2.52 to 2.87) L · min^{-1} to 3.26 (3.09to 3.44) L · min^{-1} ($P < .001$), while in the light exercise groups, no change was seen [2.51 (2.37 to 2.67)] L · min^{-1} to 2.61 (2.47 to 2.76) L · min^{-1}] (Table 2). W_{max} also improved by 24% with vigorous exercise from 231.72 (221.7 to 241.8) W to 285 (271.2 to 300.0) W ($P < .001$), but not with light exercise [221.9 (212.2 to 231.7) W *v* 220.0 (208.8 to 231.2) W]. The maximum heart rate achieved during the fitness test did not change significantly in any of the 4 groups after intervention.

Energy Intake

Energy intake in the normal energy groups was unchanged after 16 weeks [9,418 (8,232 to 10,604) kJ · d^{-1} at baseline versus 9,487 (8,498 to 10,477) kJ · d^{-1} postintervention]. The low-energy group reduced their intake from 10,462 (9,473 to 11,452) kJ · d^{-1} to 6,029 (5,405 to 6,654) kJ · d^{-1}, with a mean reduction relative to controls of −4,404 (−5,757 to −3,050) kJ · d^{-1} ($P < .001$). This comprised a mean reduction of 98.7 (−126.6 to −70.8) g of carbohydrate ($P < .001$) and −66.8 (−89.0 to −44.6) g of fat ($P < .001$), while a small fall in protein intake, −16.4 (−32.1 to −0.73) g, was not significant ($P = .09$). The percentage of energy derived from carbohydrate, protein, and fat for each of the 4 groups before and after the intervention is shown in Table 2. There was no independent effect of vigorous exercise on total energy intake or carbohydrate, fat, or protein intake. Relative to the normal-energy group, there was a small reduction in alcohol intake by 41 (5 to 78) mL · wk^{-1} with caloric restriction.

Body Composition

Energy restriction had a significant main effect on body mass and body composition (Fig 1 and Table 4). The energy restriction main effect on body mass was −10.1 (−12.2 to −8.0) kg ($P < .001$). Body fat was reduced by 5.9% (7.4% to 4.3%) ($P < .001$), FM by −7.7 (−9.6 to −5.9) kg ($P < .001$), LBM by −2.4 (−3.3 to −1.5) kg ($P < .001$), and BMI by −3.01 (2.39 to 3.63) kg · m^{-2} ($P < .001$). There was no significant effect of vigorous exercise on body mass, or composition (Fig 1 and Table 4) or BMI. Relative to light exercise, changes in total body mass of −1.1 (−3.2 to 1.0) kg ($P = .37$) and LBM of 0.3 (−0.6 to 1.2) kg ($P = .4$) with vigorous exercise were not significant. There was no evidence for any interaction of

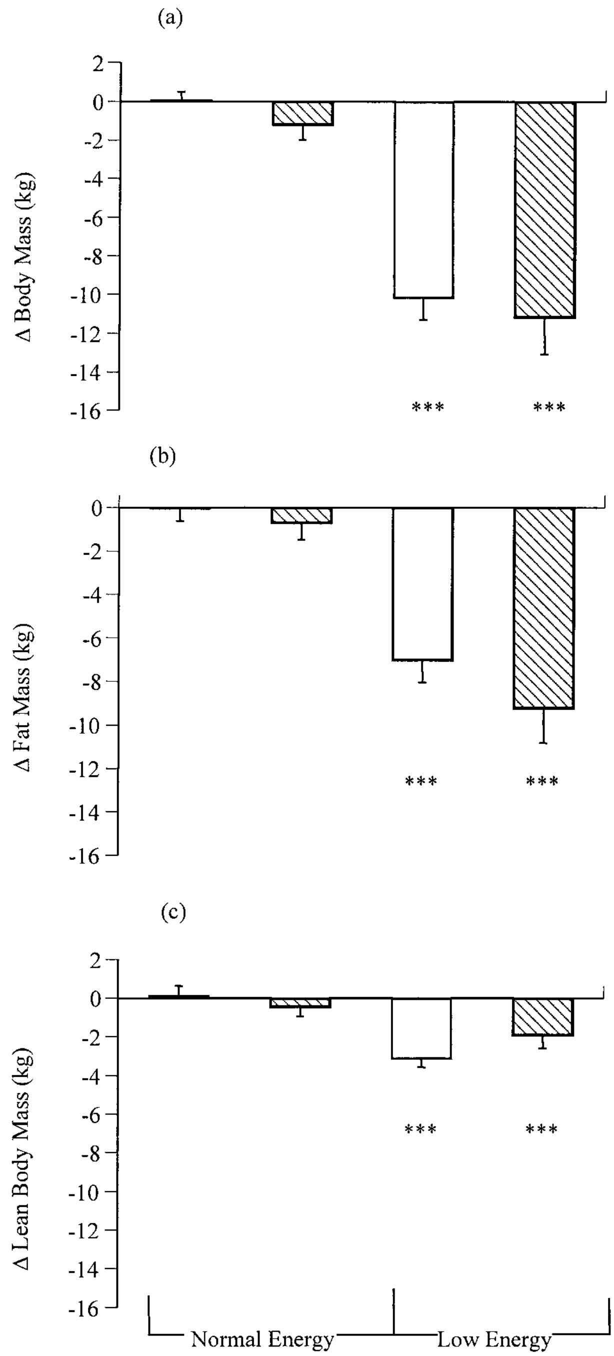

Fig 1. Mean changes (±SEM) in body composition after 16 weeks of intervention. (a) Mean change in body mass. (b) Mean change in FM. (c) Mean change in LBM. (□) Light intensity exercise; (▨) vigorous intensity exercise. Within-group differences, significance of a *t* test (Bonferroni), ****P* < .001.

Table 4. Main Effects of Energy Restriction and Vigorous Exercise on Body Mass, Body Composition, and Fat Distribution Compared to the Groups That Maintained Their Usual Diet or Did the Light Exercise, Respectively (N = 49)

Variable	Energy Restriction Main Effect			Vigorous Exercise Main Effect		
	Mean	*F* Value	*P* Value	Mean	*F* Value	*P* Value
ΔBody mass (kg)	−10.1 (−12.2-−8.0)	66.53	<.001	−1.1 (−3.2-1.0)	0.81	.37
Δ% Body fat	−5.9 (−7.4-−4.3)	40.61	<.001	−1.0 (−2.5-0.6)	1.37	.25
ΔFM (kg)	−7.7 (−9.6-5.9)	48.1	<.001	−1.4 (−3.3-0.5)	1.86	.18
ΔLBM (kg)	−2.4 (−3.3-−1.5)	22.49	<.001	0.3 (−0.6-1.2)	0.55	.4
ΔSum of 6 skinfolds (mm)	−26.9 (−38.4-15.4)	15.03	<.001	0.1 (−11.5-11.6)	0	.99
ΔWHR	−0.03 (0.04-0.01)	15.2	<.001	−0.01 (−0.02-0.01)	0.46	.50

NOTE. Values are mean with 95% confidence intervals in parentheses.

energy restriction and vigorous exercise on the changes in body mass, BMI, or body composition.

Skinfolds

Baseline and postintervention values and intervention-related change in the sum of skinfolds, and central and regional skinfolds are shown in Table 3. With the exception of the thigh and abdomen, there were significant reductions in all skinfold thicknesses with energy restriction. Expressed as a percentage of initial values, the reduction for individual areas were supraspinale 26% ($P < .001$), triceps 20.2% ($P < .05$), biceps 20.1% ($P < .01$), calf 18.7% ($P < .001$), subscapular 16.8% ($P < .05$), thigh 16.7% ($P = .1$), and abdomen 10% ($P = .5$). There were no significant changes in any skinfold with vigorous exercise, and there was no significant effect of either energy restriction or vigorous exercise on the ratio sum of regional skinfolds to sum of central skinfolds. There was no interaction between vigorous exercise and energy restriction on any of these measurements.

Girths

There were significant reductions in all girths with energy restriction, but not vigorous exercise. Relative to the group that continued their normal diet, the energy restriction main effect was −9.7 (−11.7 to −8.0) cm ($P < .001$), and −5.5 (−6.7 to −4.4) cm ($P < .001$) for waist and hip girths, respectively. When expressed as a percentage of the initial value, the reductions in girths were hip 5.3% ($P < .001$), chest 4.8% ($P < .001$), waist 8.5% ($P < .001$), upper arm 4.2% ($P < .001$), forearm 3.8% ($P < .001$), calf 3.5% ($P < .001$), and thigh 0.5% ($P < .001$).

The WHR was also significantly reduced by energy restriction [−0.03 (−0.04 to −0.01), $P < .001$] but not vigorous exercise (Table 4). The change in WHR was still significant ($P < .05$) if either the change in body mass or change in BMI was entered separately as a covariate into the ANOVA. When a similar analysis was repeated for the change in waist or hip girth, or the change in the sum of central and regional skinfolds, an energy restriction main effect on these variables was no longer significant. Vigorous exercise reduced the waist to thigh ratio by −0.07 (−0.08 to −0.12) ($P < .01$) with energy restriction showing a similar but nonsignificant trend [−0.05 (−0.09 to 0), $P = .08$].

DISCUSSION

To our knowledge this study is the first randomized controlled trial to be able to assess the effects of exercise alone, as well as in combination with energy restriction, on body mass and body composition in free-living obese men. We have also evaluated these effects while subjects participating in 2 exercise conditions were on the same diet.[6] This study has demonstrated that, at least during a 16-week intervention period, the significant loss of total body mass, FM, and LBM with energy restriction is not influenced by a simultaneous vigorous exercise program despite a 24% increase in fitness.

The 10.1-kg loss in body mass with energy restriction was similar in magnitude to that which we have previously reported using an identical protocol for 18 weeks[29] and comparable to other studies of similar duration.[17] Other studies have resulted in almost a 50% smaller loss in body mass with energy restriction.[14,30] A meta-analysis has shown, on average, a 7.8-kg loss in body mass with dieting over 31 weeks for men and that the mass loss attributable to exercise was generally small, on average 2.8 kg over 32 weeks.[6] In the present study, a nonsignificant loss in body mass of 1.1 kg with vigorous exercise was seen, consistent with these previous observations. Our results support the contention that, in free-living obese subjects who are asked to continue their usual diet unchanged, exercise alone has minimal effects, at least in the short-term, on body mass. Other studies using exercise alone have suggested that the magnitude of any body mass loss will vary according to the intensity and duration of the exercise program. Leon et al[31] demonstrated in obese men, a 6-kg reduction in body mass with a 5-day a week, 90-minute walking program over 12 weeks. Wood et al[32] achieved a 4-kg loss in body mass with 12 months jogging 3 days per week in overweight men. In a randomized, controlled trial examining the effects of diet-induced and exercise-induced weight loss in obese men for 12 weeks, daily walking/jogging at 70% peak oxygen uptake without calorie restriction substantially reduced body weight and body fat.[8] The reduction in body weight was similar for the diet-induced and exercise-induced weight loss group; however, the fat loss was greater in the exercise-induced group. In this study the duration of exercise session was determined in each individual by the time taken to expend 700 kcal (2,930 kJ). This time is estimated to be approximately 1.5 hours of walking and 1 hour of jogging. From a practical viewpoint it is unlikely that this amount of daily activity would be adhered to in the long-term. Other studies using moderate amounts of exercise with overweight individuals have shown little or no change in body mass if energy intake is not changed.[6,17,18]

There are several reasons why seemingly similar programs may produce differing results. These include the type, frequency, and duration of the training program, study design, failure to include a control exercise group to minimize cointervention bias, failure to adequately control or monitor dietary intake, varying degrees of overweight and obesity, and gender differences. The strength of the current study is that our design has allowed an examination of the independent effects of exercise alone and attempts to control for the effects of any possible confounders. Many of the studies reporting that exercise alone can reduce body mass and alter body composition were single-group studies without controls and therefore could have been biased in favor of observing an effect of exercise training.[16] In the current study and others that had appropriate control, no exercise-induced changes in body mass or composition have been seen.[7,17,33]

The exercise expenditure in this study of 1,507 to 1,758 kJ per session was in excess of the suggested 1,256 kJ threshold for body mass loss and FM reduction as set by the American College of Sports Medicine.[34] Over the period of the study, the time spent in the vigorous exercise sessions would have led to an estimated deficit of 72,334 to 84,390 kJ or a predicted fat loss of 2.3 to 2.7 kg and 3.6- to 4.1-kg loss of body mass relative to the light exercise. Although the exercise was of sufficient intensity to promote loss of body mass and fat, the fact that the exercise-only group did not lose body mass and that the magnitude of the change in the 2 energy restriction groups (with and without exercise) was similar, suggests that energy intake was even greater than assessed from the diet records. Even though we were careful to have a trained dietitian to monitor diet records and give dietary advice throughout the study, this method of self-reporting may have been a limitation of our study. Self-reports of diet records have been shown to underestimate energy intake by up to 50% and there is a greater bias with obese and weight-conscious individuals.[35] It has also been reported that in free-living individuals with an increase in exercise energy expenditure there is an associated compensatory increase in food intake, particularly in obese subjects.[16,36,37] In the current study, although the vigorous-exercise group did not significantly increase energy intake, the recorded increase of about 420 $kJ \cdot d^{-1}$ would have translated into an estimated increase in body fat of 1.6 kg over the period of the study. Without dietary monitoring it is possible that reductions in body mass, previously attributed to exercise, may have been due a failure of energy intake to increase to a level that matched energy expenditure or to undetected reductions in energy intake. The reason why some subjects may increase while others decrease energy intake with exercise is unknown. Monitoring of dietary intake is therefore essential for studies of this nature and interpretation of results of body mass or composition change is difficult without them.

The length of the current study may also have influenced the results, as some studies suggest the longer the intervention, the greater the effect of exercise. In one study, 5 weeks of energy restriction with and without exercise produced similar loss in body mass but by 14 weeks the addition of exercise had resulted in greater reductions.[38] Similarly, when 12 weeks and 24 weeks of energy restriction, with and without exercise, were compared, the addition of exercise resulted in greater loss of body mass by 24 weeks.[39] The present study of 16 weeks was longer than many previous studies, but in the light of these reports and others,[32] it is conceivable that a longer-term program may have seen an independent effect of vigorous exercise to reduce body mass.

Our finding of a loss of lean body mass with energy restriction is consistent with other reports.[16,40] In some studies, the addition of aerobic exercise to energy restriction has been shown to spare[41] or maintainLBM.[12] The failure of exercise to prevent a significant decrease in LBM with energy restriction in the current study is in agreement with the findings of others.[9,14,16,40] From meta-analysis data, with a reduction in body mass of 10 kg by diet the expected loss of LBM would be 2.9 kg, and when combined with exercise this loss would be reduced by about 1 kg.[6] In this sense, exercise training in combination with energy restriction results in enhanced preservation of LBM compared to energy restriction alone.[10,19] Our final observations were consistent with such estimates.

The more overweight subjects are at baseline, the greater the reduction in body mass with intervention.[19] In our study, the energy restriction group was heavier at baseline than the normal energy group, which could have had the potential to bias the results. However, when the analysis was repeated with correction for baseline body mass, there was no difference in the level of significance, indicating that our results were independent of any baseline differences.

Few studies have reported a change in body fat distribution before and after energy restriction and exercise, although there has been interest in body fat distribution in association with hypertension, hyperlipidemia, and hyperinsulinemia. In our study, the change in skinfolds did not provide any evidence of preferential loss from central compared to regional sites. Others have reported preferential loss of visceral abdominal fat with diet and exercise,[42] with diet-induced, exercise-induced weight loss, and with exercise without weight loss.[8] We did show a reduction in WHR with calorie restriction, indicating a shift in central fat deposits, a result that appears to contradict the finding for skinfolds. This discrepancy may to some extent be an artefact of measurement error, in that skinfolds are more difficult to record in obese subjects and are subject to greater variation than girths.[43] Another explanation could be that skinfold measurements are not sensitive enough to detect changes in visceral and abdominal fat. This view is supported by results from Ross et al[8] showing that reductions in fat were related to the change in waist circumference and, further, the relative change in visceral fat was greater than that in subcutaneous fat.

In conclusion, in this study of sedentary overweight men, 16 weeks of energy restriction, but not vigorous exercise, resulted in substantial reductions in total body mass, FM, LBM, and central fat distribution as assessed by WHR. Vigorous exercise did not enhance the changes seen with energy restriction alone. Even though our results do not support an independent or additive effect of exercise to reduce body fat in the short-term, other studies have shown that with follow-up in the long-term the most successful weight reduction programs are those that have included an exercise component.[44,45] Our study highlights that in free-living individuals it is difficult to account for confounders such as a change in energy intake or expenditure, and that to rigorously evaluate the effects of energy restriction and exercise, 24-hour monitoring of intake and expenditure is necessary in any future research. The independent effects of exercise to induce changes in body mass and composition in the longer term in overweight subjects on an energy-restricted diet deserve further study.

ACKNOWLEDGMENT

We are indebted to Penny Rogers for the anthropometric measurements. We are also grateful to Shona Papalia for her assistance with the measurement of residual volumes and to Deborah Kerr for her advice and kinanthropometic training.

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