Effects of 16 mo of verified, supervised aerobic exercise on macronutrient intake in overweight men and women: the Midwest Exercise Trial[1–3]

Joseph E Donnelly, Erik P Kirk, Dennis J Jacobsen, James O Hill, Debra K Sullivan, and Susan L Johnson

ABSTRACT

Background: It is commonly believed that moderate aerobic exercise leads to changes in diet composition, specifically, an increase in carbohydrate intake at the expense of fat intake.

Objective: The goal was to determine the effects of a supervised, long-term program of exercise on the macronutrient intake of previously sedentary, overweight and moderately obese men and women.

Design: Participants ($n = 74$) were recruited from the university and surrounding communities and were randomly assigned to the exercise or control group. Exercise of moderate intensity was performed for 45 min/d, 5 d/wk, under supervision. Diet intake was ad libitum and was measured for energy and macronutrient composition at baseline and at 5 other occasions across the 16-mo study by use of weighing and measuring techniques. Each measurement consisted of a 2-wk period of direct measurement in the university cafeteria. Food consumption outside the cafeteria during the 2-wk periods (ie, snacks) was measured by multiple-pass 24-h dietary recall procedures.

Results: There were no significant differences for men or women between the exercise and control groups from baseline to 16 mo in fat, carbohydrate, or protein intake expressed as grams or as percentages of total energy intake.

Conclusion: Sixteen months of exercise of moderate intensity does not measurably alter the macronutrient intake of young adults. *Am J Clin Nutr* 2003;78:950–6.

KEY WORDS Long-term exercise, macronutrient intake, plate waste, energy intake, energy expenditure of exercise, obesity

INTRODUCTION

The effects of long-term exercise on macronutrient composition are uncertain. Few randomized controlled studies using adequate technology have been designed to determine whether a known amount of exercise without diet modification alters the composition of energy intake (1). This question is important because changes in the amount or composition of food eaten could be a mechanism by which exercise affects body weight regulation (2–4). It has been reported that changes occur in the composition of selected foods in response to exercise, even without counseling to this effect (5–7). This concept is consistent with the notion that substrate oxidation during exercise results in a depletion of the respective stores and this in turn requires replacement subsequent to exercise (8). In particular, if carbohydrate stores were diminished in response to an exercise session, they would need to be replenished through dietary intake (9). This concept is further supported by the small storage capacity and tight regulation of carbohydrate compared with other macronutrients, which suggests a need for replenishment. For example, Wood et al (7) found that previously sedentary men increased their carbohydrate intake and decreased their fat intake in response to a 2-y program of endurance exercise. Likewise, Bjorntorp (10) showed that physically active compared with sedentary middle-aged men selected a diet higher in carbohydrate and lower in fat content.

The notion that exercise leads to increased intake of complex carbohydrate and decreased intake of fat is appealing beyond the implications for weight management. Such diet changes are generally recommended by major health organizations to diminish the health risk of cardiovascular disease and type 2 diabetes (11).

Not all investigators have found this change in diet composition in response to exercise, however. Snyder et al (12) and Donnelly et al (13) both reported no changes in carbohydrate or fat intake in response to long-term exercise of moderate intensity in both men and women. Ambler et al (14) found an increased fat intake in young physically active females. An increase in dietary fat intake after exercise would not be desirable because several reports showed that this is more likely to lead to compensation for the energy deficit provided by exercise (15, 16). We report here the findings from the Midwest Exercise Trial on the effects of a known amount of verified exercise on the macronutrient content of an ad libitum diet.

[1] From the Center for Physical Activity and Weight Management, Energy Balance Laboratory, University of Kansas, Lawrence (JED, EPK, and DJJ); the Center for Human Nutrition (JOH) and the Department of Pediatrics (SLJ), The University of Colorado Health Sciences Center, Denver; and the Department of Dietetics and Nutrition, The University of Kansas Medical Center, Kansas City (DKS).

[2] Supported by The National Institute of Diabetes and Digestive and Kidney Diseases (NIHDK49181) and The University of Colorado Health Sciences Center, Clinical Research Center (MO1 RR0051).

[3] Reprints not available. Address correspondence to JE Donnelly, Energy Balance Laboratory, Center for Physical Activity and Weight Management, The Schiefelbusch Institute for Life Span Studies, 1301 Sunnyside Avenue, University of Kansas, Lawrence, KS 66045. E-mail: jdonnelly@ku.edu.

Received November 6, 2002.

Accepted for publication May 20, 2003.

SUBJECTS AND METHODS

Participants

The Midwest Exercise Trial was initiated at The University of Nebraska–Kearney in 1996 and was transferred to The University of Kansas in 1997 when the investigators relocated (JED and DJJ). Participants were recruited from the University of Nebraska–Kearney, The University of Kansas, and their respective surrounding communities and were compensated for their participation in this project. One hundred thirty-one overweight or moderately obese subjects were randomly assigned to either an exercise intervention or a control condition for 16 mo. Seventy-four participants completed the exercise or control condition and all laboratory testing.

The participants were aged 17–35 y and had body mass indexes (BMIs; in kg/m^2) between 25.0 and 34.9 (17). Additionally, all participants met or exceeded the 85th percentile for triceps skinfold thickness of the second National Health and Nutrition Examination Survey population. The skinfold-thickness measurement helped eliminate subjects who were short and muscular rather than overweight. Participants were sedentary at the time of intake and did not exceed 500 kcal/wk of physical activity as measured by a physical activity recall questionnaire (18). Participants who had a history of chronic disease (ie, diabetes, heart disease, etc), elevated blood pressure ($>$ 140/90 mm Hg), elevated lipid concentrations (cholesterol $>$ 6.72 mmol/L; triacylglycerol $>$ 5.65 mmol/L), or elevated fasting glucose concentrations ($>$ 7.8 mmol/L) were excluded. Additionally, participants were excluded if they were smokers, if they took medications that would affect physical performance (ie, β-blockers) or metabolism (ie, thyroid medications or steroids), or if they lacked the ability to perform laboratory tests or participate in exercise of moderate intensity.

The participants were randomly assigned by using a table of random numbers at approximately a 2 to 1 ratio ($\approx$65% to the exercise group and $\approx$35% to the control group) under the supervision of a project investigator (DJJ). This assignment ratio was in anticipation of greater attrition in the exercise group than in the control group. Neither the investigators nor the participants were blinded to the assignment of participants because this was considered impractical for a long-term investigation with an obvious intervention component. All participants gave informed consent before participating in any aspect of the investigation. Approval for the study was obtained from the Human Subjects Committees at The University of Nebraska–Kearney and The University of Kansas.

Intervention

Exercise intervention

Exercise consisted primarily of walking on motor-driven treadmills; however, alternate activities such as stationary biking and walking on stationary elliptical trainers were allowed for 20% of the total exercise sessions (1 of 5 d). Each participant's exercise prescription was calculated from a maximal treadmill test conducted at baseline and was updated by the results of maximal treadmill tests conducted at 4-mo intervals. Duration of exercise progressed from 20 min at baseline to 45 min at 6 mo and the intensity of exercise progressed from 60% of heart rate reserve at baseline to 75% at 6 mo. This level of exercise corresponded to 55–70% of maximal oxygen consumption and was maintained for the remainder of the study. The targeted, minimum energy equivalent of exercise was $\approx$400 kcal per session ($\approx$2000 kcal/wk), and this was gradually achieved during the first 6 mo and then maintained for the remainder of the study. This level of energy expenditure of exercise agrees with the recommendations of the American College of Sports Medicine for exercise programs designed for weight reduction and with the recent position statement regarding appropriate strategies for weight loss and prevention of weight regain for adults (19, 20).

Exercise supervision

This study was designed to evaluate the effects of a verified amount of exercise; therefore, all exercise was performed under the direct supervision of the research personnel. The participants reported to a research assistant before the initiation of any exercise and remained under the supervision of the research assistant throughout the exercise session. The research assistant was responsible for verifying each exercise session. Because exercise intensity cannot be ascertained by observation, target heart rates were verified during each exercise session by use of a heart rate monitor (Accurex Plus; Polar, Woodbury, NY). To document the energy expended during the exercise sessions, energy expenditure was measured during 2 exercise sessions by indirect calorimetry at $\approx$4-mo intervals. In addition to measuring the energy expenditure of exercise, maximal treadmill testing was completed at baseline and at $\approx$4-mo intervals to allow for modification of the exercise prescription as aerobic capacity changed.

Control group

These participants underwent identical testing as the exercise group with the exception of testing related to the 16-mo exercise program (eg, the energy expenditure of exercise). They were instructed to maintain their normal physical activity and dietary intake patterns throughout the study.

Assessments

Body weight was measured at baseline and at 4, 9, 12, and 16 mo between the hours of 0700 and 0900 by using a digital scale accurate to $\pm$ 0.1 kg. The participants were weighed before breakfast and after attempting to void and wore a standardized hospital gown at the time of weighing.

Body composition was estimated by hydrostatic weighing. Underwater weight was recorded to the nearest $\pm$ 25 g. Residual volume was assessed in duplicate immediately preceding the body density measurement by the method of Wilmore et al (21). Body density was calculated by using the equation of Goldman and Buskirk (22), and percentage body fat was calculated with the equation of Brozek et al (23).

Aerobic capacity was assessed on a motor-driven treadmill. The participants walked to volitional exhaustion by using the Balke treadmill protocol (24). Expired gases were assessed throughout the duration of the test by using a metabolic measurement cart (Sensor Medics 2900; Sensor Medics, Yorba Linda, CA) that was calibrated before every test according to the specifications provided by the manufacturer. Heart rate and rhythm were monitored continually by using a 3-lead electrocardiogram (Marquette Electronics, Milwaukee). The maximal exercise test was considered successful if oxygen consumption

TABLE 1
Body weight, body composition, and aerobic capacity over 16 mo for men in the control (n = 15) and exercise (n = 16) groups[1]

	Baseline	16 mo	Difference at 16 mo[2]	P for 16-mo difference
Weight (kg)				
Control	94.1 ± 11.4[3]	93.6 ± 11.6	−4.8 ± 10.6	≤0.01
Exercise	94.0 ± 12.6	88.8 ± 9.5[4,5]		
BMI (kg/m^2)				
Control	29.0 ± 3.0	28.8 ± 3.0	−0.7 ± 2.8	0.02
Exercise	29.7 ± 2.9	28.1 ± 2.5[4,5]		
Body fat (%)				
Control	26.8 ± 4.6	26.0 ± 6.2	−1.4 ± 5.6	0.02
Exercise	28.3 ± 4.6	24.6 ± 5.1[4,5]		
Fat weight (kg)				
Control	25.5 ± 6.8	24.8 ± 8.1	−2.9 ± 6.8	0.01
Exercise	26.8 ± 6.8	21.9 ± 5.5[4,5]		
Fat-free weight (kg)				
Control	68.6 ± 6.4	68.9 ± 5.9	−2.0 ± 6.9	0.34
Exercise	67.1 ± 8.3	66.9 ± 7.8		
$\dot{V}O_2$max (mL · kg^{-1} · min^{-1})				
Control	39.5 ± 5.7	43.1 ± 5.8	5.4 ± 5.0	≤0.01
Exercise	39.2 ± 5.2	48.5 ± 4.1[4,5]		

[1] $\dot{V}O_2$max, maximal oxygen uptake. Data were analyzed by using a two-factor (group × time) repeated-measures (time) ANOVA. There was a significant group × time interaction for weight, BMI, percentage body fat, fat weight, and $\dot{V}O_2$max.
[2] Exercise − control.
[3] $\bar{x}$ ± SD.
[4] Significantly different from baseline within the same group, $P < 0.05$.
[5] Significantly different from the control group at 16 mo, $P < 0.05$.

plateaued and the participant met 3 of the following 4 criteria (24): *1*) maximum heart rate within 20 beats/min of the age-predicted heart rate of 220 − age, *2*) a rating of perceived exertion > 17, *3*) a respiratory exchange ratio > 1.15, and *4*) volitional exhaustion by the participant. Maximal oxygen consumption was determined as the highest value observed during the test.

The energy expenditure of exercise was measured during an exercise session. The participants reported to the laboratory 48 h after their last exercise session and ≥ 4 h after their last meal (25). The participants performed a 5-min warm-up followed by 45 min of treadmill exercise at the previously prescribed target heart rate (from the most recent maximal treadmill test) that duplicated the exercise performed in their daily sessions. Expired gases were analyzed by using a metabolic measurement cart (Sensor Medics 2900). Four separate, 5-min intervals were averaged to calculate the energy expenditure of exercise. These included minutes 5–10, 10–15, 20–25, and 30–35. These time periods were chosen to reflect any changes that might occur across the exercise session.

Dietary intake was ad libitum and was assessed for energy and macronutrient composition at baseline and at 5 other occasions across the 16-mo study by use of weighing and measuring techniques (26). Each assessment consisted of a 2-wk period during which the participants ate ad libitum in the university cafeteria. Food consumption outside the cafeteria (ie, snacks) was assessed by use of multiple-pass 24-h recall procedures that used food models and standardized, neutral probing questions (27). Results from the weigh and measure approach and from diet recalls were entered into a computerized nutrition database for analysis (ESHA RESEARCH, version 7.1; ESHA, Salem, OR). We previously showed this technique to be accurate for total energy intake when compared with doubly labeled water, with mean energy intake representing 97% and 103% of the calculated energy expenditure for women and men, respectively (28).

Statistical analysis

Means and SDs were calculated for all dependent measures. All analyses were conducted separately for men and women. A two-factor (group and time) repeated-measures (time) analysis of variance (ANOVA) was used to examine interactions and main effects for weight, BMI, body composition, aerobic capacity, energy intake, and macronutrient intakes (29). A repeated-measures ANOVA was used to examine the energy expenditure of exercise. When appropriate, least-squares means post hoc tests with Bonferroni correction were used for mean separation. Significance was set at $P < 0.05$ for all statistical tests. All data analyses were performed by using SAS (version 8.2; SAS Institute Inc, Cary, NC).

RESULTS

One hundred thirty-one subjects were initially randomly assigned to the exercise and control groups, and 74 subjects completed the study. The baseline characteristics of the men and women who completed the study are shown in **Tables 1** and **2**, respectively. No significant differences in initial age, body weight, BMI, body composition, or aerobic capacity were found at baseline between the participants who completed the study and those who did not. Reasons for attrition generally included lack of time, unwillingness to take meals in the university cafeteria, and conflict with work. Additionally, participants were released from the study if their adherence to the

TABLE 2
Body weight, body composition, and aerobic capacity over 16 mo for women in the control (n = 18) and exercise (n = 25) groups[1]

	Baseline	16 mo	Difference at 16 mo[2]	*P* for 16-mo difference
Weight (kg)				
Control	79.9 ± 8.1[3]	82.8 ± 9.2[4]	−5.2 ± 11.5	0.03
Exercise	77.0 ± 11.4	77.6 ± 12.8[5]		
BMI (kg/m^2)				
Control	29.3 ± 2.3	30.3 ± 3.1[4]	−1.5 ± 3.3	0.03
Exercise	28.7 ± 3.2	28.8 ± 3.5[5]		
Body fat (%)				
Control	36.7 ± 4.0	37.8 ± 4.5	−3.3 ± 4.5	0.02
Exercise	35.3 ± 4.6	34.5 ± 4.5		
Fat weight (kg)				
Control	29.4 ± 5.1	31.6 ± 6.4[4]	−4.2 ± 7.3	0.02
Exercise	27.4 ± 7.1	27.2 ± 7.9[5]		
Fat-free weight (kg)				
Control	50.5 ± 4.6	51.2 ± 4.5	−0.8 ± 5.3	0.57
Exercise	49.5 ± 5.8	50.4 ± 5.8		
$\dot{V}O_2$max (mL · kg^{-1} · min^{-1})				
Control	32.4 ± 3.1	33.7 ± 3.8	5.2 ± 4.7	≤0.01
Exercise	32.8 ± 4.2	38.9 ± 3.2[4,5]		

[1] $\dot{V}O_2$max, maximal oxygen uptake. Data were analyzed by using a two-factor (group × time) repeated-measures (time) ANOVA. There was a significant group × time interaction for weight, BMI, fat weight, and $\dot{V}O_2$max.
[2] Exercise − control.
[3] $\bar{x}$ ± SD.
[4] Significantly different from baseline within the same group, $P < 0.05$.
[5] Significantly different from the control group at 16 mo, $P < 0.05$.

scheduled exercise sessions fell < 85%. No major adverse events occurred during this study in either the exercise or the control group. Participants who completed the study included 1 Native American, 5 Asians, 6 African Americans, 1 Hispanic, and 61 whites.

Exercise adherence

Adherence to the exercise protocol was excellent: 90.3% and 89.6% of the total sessions were completed by the men and the women, respectively. The average speed and grade of the treadmill exercise for the men was 123.3 ± 24.1 m/min and 4.4 ± 3.7%, respectively, and that for the women was 109.9 ± 0.7 m/min and 2.9 ± 2.4%, respectively. The average exercise heart rates across the 16-mo study were 154 ± 11 beats/min for men and 156 ± 9 beats/min for women. At 16 mo, men averaged 667 ± 116 kcal per exercise session and women averaged 439 ± 88 kcal. The energy expenditure of exercise expressed per kilogram body weight per exercise session was 6.7 ± 0.8 kcal/kg for men and 5.4 ± 1.1 kcal/kg for women.

Energy expenditure of exercise

Men increased their energy expenditure significantly from week 5 to week 13 by 146 kcal per session and from week 13 to week 30 by 113 kcal per session for a total increase of 259 kcal per session during the first 30 wk; there were no significant changes in energy expenditure beyond week 30 (**Figure 1**). This corresponded with a total energy expenditure of exercise of ≈650 kcal per session from weeks 30–66. Women increased their energy expenditure significantly from week 5 to week 13 by 85 kcal per session and from week 13 to week 30 by 78 kcal per session for a total increase of 163 kcal per session during the first 30 wk; there were no significant changes beyond week 30 (Figure 1). This corresponded with a total energy expenditure of exercise of ≈430 kcal per session from weeks 30–66.

Aerobic capacity

The exercise program resulted in increases in maximal oxygen consumption of 20% for men and 16% for women, which indicated that the participants exercised in accordance with the protocol. Likewise, the lack of change in maximal oxygen consumption in the control subjects indicated that they did not adopt a regular exercise program during the 16-mo study (Tables 1 and 2).

Body weight, BMI, and body composition

No significant differences in body weight, BMI, percentage body fat, fat mass, or fat-free mass for either men or women were found at baseline between the subjects in the exercise group and those in the control group (Tables 1 and 2). The body weight and body-composition results were reported previously (30). For men, decreases in body weight (5.2 ± 4.7 kg), BMI (1.6 ± 1.4) and fat mass (4.9 ± 4.4 kg) at 16 mo were significantly greater in the exercise group than in the control group. There were no significant differences in fat-free mass between the exercise and control groups.

The women in the exercise group remained weight stable over the 16-mo study period (gaining only 0.6 ± 3.8 kg), whereas those in the control group gained a significant amount of weight (2.9 ± 5.5 kg). Likewise, the BMI of the women in the exercise group remained stable, with a nonsignificant increase of 0.1 ± 1.3, whereas that in the control group increased significantly by 1.1 ± 2.0. Fat mass tended to decrease in women in the exercise group (by 0.3 ± 2.7 kg; NS), whereas

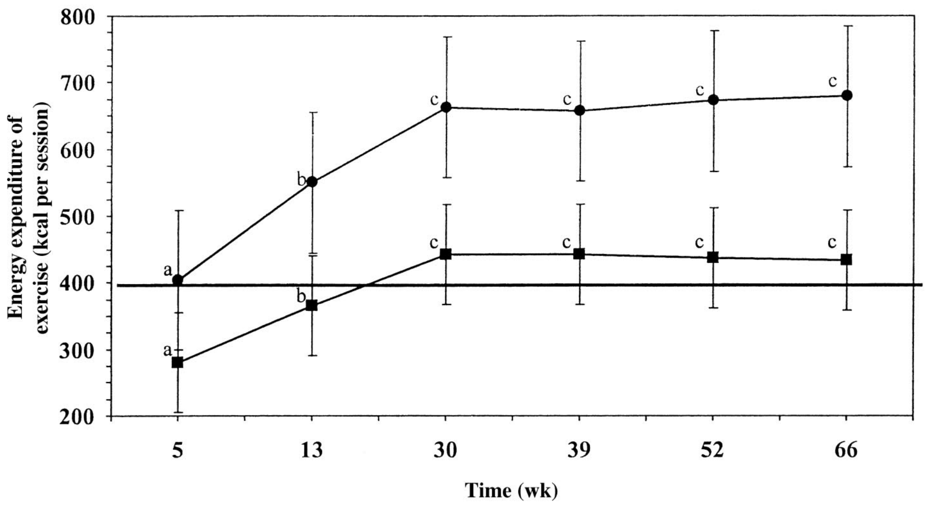

FIGURE 1. Mean (± SD) energy expenditure of exercise across 16 mo for men (●; n = 16) and women (■; n = 25). Men and women were analyzed separately. Data were analyzed by using a repeated-measures (time) ANOVA. Least-squares means with Bonferroni correction were used for mean separation. Means within each sex with different superscript letters are significantly different, $P < 0.05$. The solid line represents the targeted energy expenditure value.

it increased significantly by 2.1 ± 4.8 kg in the control group. At 16 mo, women in the exercise group had significantly lower body weights, BMIs, and fat masses than did the control group. Fat-free mass tended to increase in both the exercise and control groups, by 0.8 ± 1.8 and 0.7 ± 1.7 kg, respectively (NS).

Energy intake

There were no significant differences at baseline or at 16 mo in intakes of energy (kcal), fat (grams), or carbohydrate (grams) between the exercise and control groups for men (**Table 3**). Protein intake increased significantly in men from baseline to 16 mo (from 102 ± 23 to 106 ± 27 g); however, this was not significant when expressed as a percentage of total energy intake. There were no significant differences in fat, carbohydrate, or protein intake in men when these were expressed as percentages of total energy intake (**Table 4**).

There were no significant differences at baseline or at 16 mo in intakes of energy (kcal), fat (grams), carbohydrate (grams), or protein (grams) between the exercise and control groups for women (Table 3). Similarly, no significant differences in macronutrient intake expressed as percentages of total energy intake were found in women (Table 4).

DISCUSSION

We found that 16 mo of supervised exercise training by previously sedentary men and women did not lead to changes in the composition of self-selected food intake. Food intake was measured on 6 different occasions during the 16-mo exercise training period with the use of a state-of-the-art plate waste method that was previously validated against doubly labeled water (31). There were no significant changes in amounts or percentages of carbohydrate or fat eaten over the 16-mo exercise training period in either men or women. The change shown in grams of protein intake for men was small and commensurate with slightly increased food intake values at the last food intake assessment.

TABLE 3
Total energy and macronutrient intakes over 16 mo for men and women in the exercise and control groups[1]

Variable and energy intake period	Men		Women	
	Exercise (n = 16)	Control (n = 15)	Exercise (n = 25)	Control (n = 18)
Energy intake (kcal)				
Baseline	3084 ± 564	3524 ± 761	2554 ± 508	2363 ± 503
3 mo	2865 ± 525	3431 ± 794	2494 ± 405	2452 ± 582
6 mo	2985 ± 635	3331 ± 848	2490 ± 452	2372 ± 524
9 mo	3029 ± 697	3514 ± 1010	2389 ± 463	2386 ± 850
12 mo	2973 ± 780	3242 ± 748	2397 ± 629	2336 ± 644
16 mo	3156 ± 787	3433 ± 760	2418 ± 521	2464 ± 594
Protein intake (g)				
Baseline	102 ± 23	120 ± 25	83 ± 19	72 ± 19
3 mo	94 ± 26	112 ± 27	78 ± 20	75 ± 21
6 mo	98 ± 22	111 ± 35	78 ± 17	76 ± 23
9 mo	105 ± 26	120 ± 49	76 ± 15	75 ± 31
12 mo	100 ± 29	109 ± 26	79 ± 20	75 ± 26
16 mo	106 ± 27[2]	119 ± 28	78 ± 18	77 ± 25
Carbohydrate intake (g)				
Baseline	401 ± 80	442 ± 104	360 ± 66	342 ± 83
3 mo	376 ± 84	444 ± 111	350 ± 58	344 ± 99
6 mo	386 ± 91	437 ± 127	352 ± 72	323 ± 79
9 mo	388 ± 90	466 ± 141	341 ± 76	328 ± 114
12 mo	383 ± 114	426 ± 113	327 ± 85	325 ± 110
16 mo	405 ± 127	454 ± 104	338 ± 82	336 ± 94
Fat intake (g)				
Baseline	119 ± 28	140 ± 43	90 ± 30	83 ± 20
3 mo	106 ± 23	133 ± 39	87 ± 22	88 ± 22
6 mo	113 ± 30	130 ± 40	88 ± 23	86 ± 23
9 mo	117 ± 36	136 ± 47	84 ± 24	91 ± 39
12 mo	115 ± 38	120 ± 33	87 ± 31	86 ± 30
16 mo	121 ± 32	125 ± 34	86 ± 26	94 ± 24

[1] $\bar{x}$ ± SD. Men and women were analyzed separately. Data were analyzed by using a two-factor (group × time) repeated-measures (time) ANOVA. There were no significant interactions.

[2] Significantly different from baseline within the same group, $P < 0.05$.

TABLE 4
Percentage macronutrient intakes over 16 mo for men and women in the exercise and control groups[1]

Variable and energy intake period	Men		Women	
	Exercise (n = 16)	Control (n = 15)	Exercise (n = 25)	Control (n = 18)
Protein intake (%)				
Baseline	19.1 ± 4.7	20.4 ± 5.2	18.3 ± 3.9	17.2 ± 3.2
3 mo	19.5 ± 4.9	17.7 ± 4.8	16.6 ± 3.1	17.7 ± 4.2
6 mo	19.6 ± 5.6	19.7 ± 5.15	17.3 ± 3.6	19.1 ± 4.8
9 mo	20.7 ± 4.6	22.0 ± 14.0	18.0 ± 3.5	18.8 ± 4.0
12 mo	18.7 ± 4.0	18.2 ± 2.9	19.3 ± 4.9	21.6 ± 10.4
16 mo	18.8 ± 2.7	19.4 ± 4.7	20.2 ± 8.8	17.6 ± 3.5
Carbohydrate intake (%)				
Baseline	46.1 ± 6.4	42.9 ± 10.2	51.0 ± 10.6	63.4 ± 37.4
3 mo	48.3 ± 7.6	47.8 ± 7.7	52.4 ± 7.1	52.2 ± 10.2
6 mo	46.1 ± 7.8	50.4 ± 9.7	51.2 ± 7.8	47.6 ± 11.2
9 mo	48.9 ± 9.2	55.2 ± 28.9	52.7 ± 5.9	48.2 ± 10.8
12 mo	49.0 ± 8.0	47.7 ± 6.7	50.1 ± 6.9	45.9 ± 14.3
16 mo	41.9 ± 7.3	49.0 ± 7.2	53.1 ± 14.9	52.3 ± 15.6
Fat intake (%)				
Baseline	37.3 ± 6.4	38.8 ± 9.2	32.4 ± 9.4	29.1 ± 7.6
3 mo	33.5 ± 8.4	33.2 ± 7.6	32.5 ± 6.4	31.4 ± 8.5
6 mo	34.4 ± 6.1	31.1 ± 9.1	33.2 ± 7.2	33.3 ± 7.4
9 mo	30.0 ± 10.9	33.7 ± 8.0	30.8 ± 7.5	35.8 ± 9.7
12 mo	34.3 ± 6.8	34.8 ± 3.9	31.32 ± 5.9	35.7 ± 10.2
16 mo	39.3 ± 9.9	32.6 ± 4.3	30.9 ± 9.5	33.5 ± 9.2

[1] $\bar{x}$ ± SD. Men and women were analyzed separately. Data were analyzed by using a two-factor (group × time) repeated-measures (time) ANOVA. There were no significant interactions.

These results are consistent with the results of other investigations by Donnelly and colleagues. In one study, macronutrient composition was measured in 13 women who underwent a 32-wk exercise program that consisted of brisk walking for three 10-min sessions, 5 d/wk. Energy intake was measured at baseline, twice during the study, and at 32 wk by use of diet records and diet recalls. Neither energy intake nor macronutrient intake changed significantly at any measurement point (12). In a subsequent 18-mo study, exercise resulted in a reduction in fat intake, but no increase in carbohydrate intake. In that study, 22 moderately obese women were randomly assigned to either short bouts of exercise of two 15-min exercise sessions 5 d/wk or long bouts of exercise of three 30-min sessions 3 d/wk at 70% of maximal oxygen uptake. Participants who were randomly assigned to the short-bout sessions were supervised at random intervals by a research assistant and used brisk walking and self-reported the exercise. The participants randomly assigned to the long-bout sessions completed their exercise on treadmills in the investigator's laboratory. The short-bout group showed significant reductions in fat intake expressed as either grams or percentage of total energy intake; however, no increases in carbohydrate were shown (13). The long-bout group showed no significant changes in macronutrient intake. It is possible that the greater duration of exercise of the short-bout group, who accumulated 150 min of exercise/wk compared with 90 min/wk in the long-bout group, had a greater stimulation on fat utilization; however, this was not measured and is ultimately unknown.

The findings from the studies by Donnelly and colleagues can be compared with those of the studies of Wood et al, in which middle-aged men decreased their fat intake in response to exercise. Wood et al found decreases in fat intake in 2 studies of 1-y duration (8, 32) and decreases in fat intake and increases in carbohydrate intake in a study of 2-y duration (7). Taken as a whole, the studies of Wood et al seem to suggest that exercise is likely to decrease fat intake and may increase carbohydrate intake without any planned dietary modification.

Support for the notion that exercise does not change macronutrient intake can be found in the results for substrate utilization from both resting metabolic rate measurements and 24-h calorimetry in the Midwest Exercise Trial (33). No significant changes in the substrate oxidation of macronutrients were found. If changes were found for resting or 24-h substrate oxidation, this would suggest that energy intake had indeed changed (34, 35). It is likely that moderately intense exercise affects substrate oxidation during the exercise session itself and shortly after exercise but does not produce longstanding changes in substrate oxidation that would, in turn, reflect changes in energy intake.

Although the present investigation may be the most intensive longitudinal study of the effects of verified exercise on macronutrient intake and although we used state-of-the-art methods, caution is always advisable because flaws exist in all of the methods currently used to measure energy and macronutrient intakes. Additionally, although we had good power to detect differences in men (0.7), we did not in women (0.10) because of the absence of any clinically meaningful or statistically significant differences between the exercise and control groups. In summary, we conclude that moderately intense exercise is not likely to change the macronutrient content of an ad libitum diet (ie, increase carbohydrate intake and decrease fat intake) in the absence of dietary advice.

JED was the principal investigator for the project and was responsible for the design, analysis, and interpretation of the study and the writing of the manuscript. EPK was responsible for the supervision of the exercise sessions, the data collection and reduction, the interpretation of the analysis, and the content of the manuscript. DJJ was responsible for the design of the study, the management of the database, the statistical analysis, the interpretation of the study, and the content of the manuscript. JOH was responsible for the design of the study, the supervision of the laboratory tests, the interpretation of the data, and the content of the manuscript. DKS was responsible for the design of the study, the supervision of nutritional intake, the interpretation of the data, and the content of the manuscript. SLJ was responsible for the design of nutritional intake, the interpretation of the data, and the content of the manuscript. None of the authors had a relevant financial or personal interest in any company or organization sponsoring this research.

REFERENCES

1. King NA, Tremblay A, Blundell JE. Effects of exercise on appetite control: implications for energy balance. Med Sci Sports Exerc 1997; 29:1076–89.
2. King NA, Blundell JE. High-fat foods overcome the energy expenditure induced by high-intensity cycling or running. Eur J Clin Nutr 1995;49:114–23.
3. Blundell JE, Burkley VJ, Cotton J, Lawton CL. Dietary fat and the control of energy intake; evaluating the effects of fat on meal size and post meal satiety. Am J Clin Nutr 1993;57(suppl):772S–8S.
4. Lawton C, Burley V, Wales J, Blundell J. Dietary fat and appetite

control in obese subjects: weak effects on satiation and satiety. Int J Obes Relat Metab Disord 1993;17:409–16.
5. Miller WC, Lindeman AK, Wallace J, Niederpruem M. Diet composition, energy intake, and exercise in relation to body fat in men and women. Am J Clin Nutr 1990;52:426–30.
6. Tremblay A, Alméras N. Exercise, macronutrient preferences and food intake. Int J Obes Relat Metab Disord 1995;19(suppl):S97–101.
7. Wood PD, Terry RB, Haskell WL. Metabolism of substrates: diet, lipoprotein metabolism, and exercise. Fed Proc 1985;44:358–63.
8. Wood PD, Stefanick ML, Dreon DM, et al. Changes in plasma lipids and lipoproteins in overweight men during weight loss through dieting as compared with exercise. N Engl J Med 1988;319:1173–9.
9. Sarkin JA, Nichols JF, Sallis JF, Calfas KJ. Self-report measures and scoring protocols affect prevalence estimates of meeting physical activity guidelines. Med Sci Sports Exerc 1998;32:149–56.
10. Bjorntorp P. Exercise in the treatment of obesity. Clin Endocrinol Metab 1976;5:431–53.
11. Krauss RM, Eckel RH, Howard B, et al. Revision 2000: a statement for healthcare professionals from the nutrition committee of the American Heart Association. Circulation 2000;102:2284–99.
12. Snyder KA, Donnelly JE, Jacobsen DJ, Hertner G, Jakicic JM. The effects of long-term, moderate intensity, intermittent exercise on aerobic capacity, body composition, blood lipids, insulin, and glucose in overweight females. Int J Obes Relat Metab Disord 1997;21:1180–9.
13. Donnelly JE, Jacobsen DJ, Snyder Heelan KA, Seip R, Smith S. The effects of 18 months of intermittent vs continuous exercise on aerobic capacity, body weight and composition, and metabolic fitness in previously sedentary, moderately obese females. Int J Obes Relat Metab Disord 2000;24:566–72.
14. Ambler C, Eliakim A, Brasel JA, Lee W-N, Burke G, Cooper DM. Fitness and the effect of exercise training on the dietary intake of healthy adolescents. Int J Obes Relat Metab Disord 1998;22:354–62.
15. Tremblay A, Almeras N, Boer J, Kranenbarg EK, Despres JP. Diet composition and post exercise energy balance. Am J Clin Nutr 1994; 59:975–9.
16. Shape up America: American Obesity Association. Guidance for treatment of adult obesity. Bethesda, MD: American Obesity Association, 1996.
17. National Institutes of Health. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. Obes Res 1998;6:1S–210S.
18. Blair SN, Haskell WL, Ho P. Assessment of physical activity by a seven-day recall in a community survey and controlled experiments. Am J Epidemiol 1985;122:794–804.
19. American College of Sports Medicine. Position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory fitness in healthy adults. Med Sci Sports Exerc 1990;22:265–70.
20. Jakicic JM, Clark K, Coleman E, et al. Appropriate intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 2001;33:2145–56.
21. Wilmore JH, Vodak PA, Parr RB, Girandola RN, Billing JE. Further simplification of a method for determination of residual lung volume. Med Sci Sports Exerc 1980;12:216–8.
22. Goldman RF, Buskirk ER. Body volume measurement by under-water weighing: description of a method. In: Brozek J, Henschel A, eds. Techniques for measuring body composition. Bethesda, MD: National Academy of Sciences and National Research Council, 1961:78–89.
23. Brozek J, Grande F, Anderson JT, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci 1963;110:113–60.
24. American College of Sports Medicine. Guidelines for exercise testing and prescription. Philadelphia: Lea & Febiger, 1988.
25. Drougas HJ, Reed G, Hill JO. Comparison of dietary self-reports with energy expenditure measured using a whole-room indirect calorimeter. J Am Diet Assoc 1992;92:1073–7.
26. US Department of Agriculture. General guidelines for determining food acceptability (procedures for plate waste studies). Washington, DC: USDA, Food and Nutrition Service, 1975.
27. Gibson RS. Principles of nutrition assessment. Oxford, United Kingdom: Oxford University Press, 1990.
28. Salbe AD, Weyer C, Harper I, Lindsay RS, Ravussin E, Tataranni A. Assessing risk factors for obesity between childhood and adolescence: II. energy metabolism and physical activity. Pediatrics 2002;110:307–14.
29. Selvin S. Practical biostatistical methods. Belmont, WA: Wadsworth Publishing Company, 1995.
30. Donnelly JE, Hill JO, Jacobsen DJ, et al. Effects of a 16-month randomized controlled exercise trial on body weight and composition in young, overweight men and women: the Midwest Exercise Trial (MET). Arch Intern Med 2003;163:1343–50.
31. Hise ME, Sullivan DK, Jacobsen DJ, Johnson SL, Donnelly JE. Validation of energy intake measurements determined from observer-recorded food records and recall methods compared with the doubly labeled water method in overweight and obese individuals. Am J Clin Nutr 2002;75:263–7.
32. Wood PD, Haskell WL, Blair SN, et al. Increased exercise level and plasma lipoprotein concentrations: a one-year, randomized, controlled study in sedentary, middle-aged men. Metabolism 1983;32:31–9.
33. Melanson E, Jacobsen DJ, Sharp T, Grunwald G, Hill JO, Donnelly JE. Changes in 24 h fat oxidation in females participating in a long-term exercise training program. Obes Res 1999;7(S1):96S (abstr).
34. Flatt JP. Dietary fat, carbohydrate balance, and weight maintenance: effects of exercise. Am J Clin Nutr 1987;45:296–306.
35. Flatt JP. Dietary fat, carbohydrate balance, and weight maintenance. Ann N Y Acad Sci 1993;683:122–40.