Effects of aerobic fitness on fat oxidation and body fatness

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ABSTRACT

KRIKETOS, A. D., T. A. SHARP, H. M. SEAGLE, J. C. PETERS, and J. O. HILL. Effects of aerobic fitness on fat oxidation and body fatness. *Med. Sci. Sports Exerc.*, Vol. 32, No. 4, pp. 805–811, 2000. **Objective:** This study investigated the contributions of physical fitness and body composition to 24-h fat oxidation in adults under sedentary conditions in a whole-room calorimeter. **Methods:** The following measurements were studied in 109 adults (49 male/45 female) at least 36 h after a bout of exercise: 1) aerobic fitness level assessed by $\dot{V}O_{2max}$, 2) body composition determined by underwater weighing, 3) resting metabolic rate (RMR) after an overnight fast, and 4) 24-h energy expenditure (EE) and substrate oxidation determined in a whole-room calorimeter. While in the calorimeter, subjects were provided with a diet (15% protein, 30% fat, and 55% carbohydrate) estimated to produce energy balance on a sedentary day and of similar nutritional composition to their daily dietary intake. **Results:** We found strong negative correlations between $\dot{V}O_{2max}$ and % body fat in both male and female subjects, but no relationship between $\dot{V}O_{2max}$ and 24-h EE under the sedentary conditions of this study. In male subjects, $\dot{V}O_{2max}$ (mL $O_2 \cdot kg^{-1}$ fat-free mass$\cdot min^{-1}$) was negatively related to fat oxidation ($r = -0.397$, $P < 0.005$), and fat oxidation was more closely related to fat mass ($r = 0.434$, $P < 0.0002$) than to fat-free mass ($r = 0.165$, NS). In contrast, none of these relationships were significant in females. **Conclusion:** The results show that in male subjects under sedentary conditions, 24-h fat oxidation is positively related to body fat mass and negatively related to $\dot{V}O_{2max}$ (the marker used here for level of physical fitness). This supports our hypothesis that regularly active males maintain lower body fat stores as the low contribution to daily fat oxidation from a lower body fat mass is counterbalanced by the high contribution to fat oxidation from daily physical activity. The lack of a relationship between $\dot{V}O_{2max}$ and 24-h EE under the sedentary conditions of this study suggests that the major effects of physical activity on total daily EE and fat oxidation may occur during and relatively quickly after an exercise bout. Further, these data also suggest that cessation of regular exercise will likely be associated with a high risk of positive fat balance and weight gain. **Key Words:** ENERGY EXPENDITURE, OBESITY, PHYSICAL ACTIVITY, SUBSTRATE OXIDATION, ENERGY BALANCE, FAT BALANCE

Body weight maintenance involves a balance between energy intake and energy expenditure (EE), and also requires a similar balance between intake and oxidation for protein, carbohydrate, and fat (2,5,6,11). Daily EE can be increased through regular physical activity (10, 14), and physically active individuals remain weight stable by matching the greater EE with higher energy intake. Individuals who undertake regular physical activity are generally leaner than their sedentary counterparts (15); however, the specific mechanism involved in the contribution of physical activity to promote leanness is not completely understood.

Several investigators have suggested that a major benefit of a high physical fitness level is a high rate of fat oxidation, both at rest (20,25) and during exercise (9,13). However, others have found that fat oxidation at rest (22) and 24-h fat oxidation (1) is related to fat mass, so that physically active individuals with low body fat mass might be expected to have low levels of fat oxidation. Obviously, both points of view cannot be true. Our hypothesis is that daily fat oxidation is regulated by both fat mass and physical activity. In other words, more physically active individuals may show a low fat oxidation in the absence of physical activity (i.e., under sedentary conditions) and a high fat oxidation during exercise. In this study, we determined 24-h EE and fat oxidation in variably trained subjects on a sedentary day in order to examine the relationship between fat oxidation and fat mass.

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METHODS

Subjects. Subjects for this study were 49 male and 45 female adults. All subjects signed approved consent forms. Our aim was to recruit nonsmoking subjects who varied

widely in levels of aerobic fitness and who had no history of diabetes or cardiovascular disease. All subjects were weight stable (± 2 kg) at least 6 months before and remained weight stable throughout the study. This study was approved by the Vanderbilt University Committee for the Protection of Human Subjects.

Protocol. After an initial Health and Physical Examination, the following determinations were performed on each subject within a 1- to 2-wk period: 1) assessment of aerobic fitness level ($\dot{V}O_{2max}$) by a maximal treadmill test, 2) body composition determined by underwater weighing, 3) resting metabolic rate (RMR) after an overnight fast, 4) 24-h EE and components of EE (including sleeping metabolic rate (SMR), thermic effect of food (TEF), thermic effect of physical activity (EEact), and substrate oxidation rates measured during a 24-h stay in a whole-room calorimeter. A dietary recall of each subject's usual dietary intake and food preferences was collected by the dietetic staff. The nutrient content of food eaten was determined from the Nutritionist III software (19). While in the calorimeter, each subject was fed a diet containing 15% protein, 30% fat, and 55% carbohydrate. The composition of the chamber diet was similar to that regularly eaten by the subjects. The energy content of the diet was designed to achieve energy balance in the calorimeter and was determined from RMR multiplied by an activity factor of 1.5. We have previously found this activity factor to produce energy balance in the calorimeter in subjects engaging in light physical activity (12). The food was prepared and measured by the staff at the General Clinical Research Center research kitchen.

Based on a previous study by our laboratory, measurements of $\dot{V}O_{2max}$ and EE were made at least 36 h after the last bout of any exercise in order to remove any effect of exercise on substrate balance (23). Thus, the substrate balance obtained in this study population represents the substrate balance achieved by individuals of differing levels of aerobic fitness during a sedentary 24-h period in a whole-room calorimeter. Although we recognize that 36 h may not be sufficient to eliminate all effects of the last bout of exercise (particularly if it is very strenuous), it should be sufficient to eliminate most of the effects of this last exercise bout on whole body energy expenditure and fat oxidation.

Measurement of aerobic fitness. The subjects' aerobic fitness was defined by their $\dot{V}O_{2max}$, as determined during a treadmill test using the Bruce protocol (3). $\dot{V}O_{2max}$ was defined as the highest rate of oxygen consumption achieved by the subject. The Bruce protocol increases speed and grade of the treadmill every 3 min until volitional exhaustion. Oxygen consumption and carbon dioxide production were measured continuously using a SensorMedics 2900 Oxygen Uptake System (Yorba Linda, CA). To assure that $\dot{V}O_{2max}$ had been achieved, the maximum heart rate (HR) had to be near the maximum age-predicted HR (±5 bpm from maximum HR), and the respiratory quotient (RQ) had to be >1.1. In addition, HR and blood pressure were monitored before, and every 1 and 3 min, respectively, during, and after the treadmill test. The within-subject coefficient of variation (CV) for $\dot{V}O_{2max}$ in our laboratory is 4%. $\dot{V}O_{2max}$ as a marker of physical fitness level in this study is reported in terms of mL of oxygen consumed per kg of fat-free mass (FFM) per min. The expression of $\dot{V}O_{2max}$ in units of FFM was chosen because of the large range of body weights and adiposity in this subject population. Thus, we believe that the relationships between variables collected during a 24 h stay in a whole-room calorimeter and $\dot{V}O_{2max}$ expressed per unit of FFM more appropriately reflects our findings. Our conclusions would not be different if $\dot{V}O_{2max}$ were expressed per unit of body weight.

Body composition. Body composition was determined from measurements of body density estimated by underwater weighing (7). Body weights in air and underwater were measured to the nearest 25 g using Heath platform and Chatillon spring scales, respectively. Residual lung volume was determined (simultaneously with underwater weighing) using a closed-circuit nitrogen-dilution method (7). Nitrogen concentration during rebreathing was measured with a Med-Science 505-D Nitralizer (St. Louis, MO). Percent body fat was estimated from body density using the revised equation of Lohman et al. (17). Reproducibility tests in our laboratory show an average difference of 2–4% between tests of the same subjects.

Resting metabolic rate. RMR was measured using a ventilated hood system (SensorMedics 2900 Oxygen Uptake System). Subjects reported to our laboratory after an overnight fast. Subjects rested quietly for 30–45 min, and then RMR was measured continuously for 15 min. In our laboratory, reproducibility tests show an average variation of 5–6% between trials of the same subjects.

Daily energy expenditure and components of energy expenditure. Total 24-h EE was measured using a whole-room indirect calorimeter, which has been described previously (12,23,24). While in the calorimeter, the subjects were free to move around but were not provided with exercise equipment and were specifically instructed not to exercise. In addition to total 24-h EE, we determined SMR, which we defined as the average metabolic rate measured during sleep. Sleep periods were determined from the subject's activity diary in conjunction with measures of activity obtained from a radar detector (sleep defined as movement <1% of any given measurement period). TEF and EEact were also measured and defined as energy expended in response to daily meals and energy expended during periods of routine activity in the chamber (such as grooming and preparing for sleep) (i.e., 24-h EE − (RMR + TEF)), respectively. In 25 subjects studied two times each in the calorimeter, the within-subject CV for total EE was 4% and was 2.9% for SMR.

Substrate oxidation rates and daily nutrient balance. Daily rates of oxidation of protein, carbohydrate, and fat were determined for each 24-h stay in the whole-room calorimeter. Protein oxidation was determined from 24-h urinary nitrogen excretion (measured using the Kjeldahl technique), and carbohydrate and fat oxidation were determined from 24-h $\dot{V}O_2$ and nonprotein RQ (12,23,24). All food given to the subjects was precisely weighed, and subjects were instructed to consume all food given to them.

Nutrient balance was calculated as the difference between intake and oxidation of each nutrient over 24 h.

Statistical methods. Mean, standard error of the mean (SEM), and range for each study variable were calculated. Simple linear and multiple regression analyses were used to compare the relationships among variables of interest, including $\dot{V}O_{2max}$, body composition, EE, and fat oxidation.

RESULTS

Table 1 depicts the subject characteristics of the study population. We intentionally chose subjects who varied in level of aerobic fitness and body composition. Among this population, the range of FFM was wide (33.1–104.8 kg), as was the level of aerobic physical fitness (21.6–76.6 mL $O_2 \cdot kg^{-1}$ FFM$\cdot min^{-1}$) determined from $\dot{V}O_{2max}$ assessment. Subjects ranged in age from 20 to 59 yr. Male subjects were slightly but not significantly leaner than the female subjects (Table 1). Male subjects were significantly heavier and taller than the female subjects (Table 1) and, on average had significantly greater BMI (26.6 ± 0.9 vs 22.7 ± 0.8 kg$\cdot m^{-2}$, $P < 0.002$).

Table 2 shows components of EE for men and women in the study. Daily energy intake and EE were significantly greater for male subjects (Table 2). There was no gender difference in mean energy balance. However, RMR, SMR, TEF, and EEact were all significantly higher in the male group (Table 2). There was a trend for RMR RQ and SMR RQ to be lower in male subjects, with the latter comparison being significant.

We found significant negative correlations between $\dot{V}O_{2max}$ (expressed per unit FFM) and percentage body fat for both male subjects ($r = -0.554$, $P < 0.0001$) and female subjects ($r = -0.526$, $P < 0.0003$) (Fig. 1). Similar correlations were obtained when body fat mass was expressed in absolute terms (Table 3). FFM was not significantly correlated with $\dot{V}O_{2max}$ (mL $O_2 \cdot kg^{-1}$ FFM$\cdot min^{-1}$) or with $\dot{V}O_{2max}$ (mL $O_2 \cdot kg^{-1}$ body weight$\cdot min^{-1}$) in either male or female subjects. $\dot{V}O_{2max}$ was not significantly related to either total 24-h EE, RMR (Fig. 2), or SMR (Table 3) in either male or female subjects.

$\dot{V}O_{2max}$ was not related to 24-h fat oxidation when the entire subject population was considered ($r = -0.058$, NS) (Table 3). However, when male and female subjects were analyzed separately, there was a significant negative correlation between $\dot{V}O_{2max}$ and fat oxidation in male subjects ($r = -0.397$, $P = 0.005$), but no significant relationship in female subjects ($r = 0.052$, NS) (Table 3).

TABLE 1. Subject characteristics.[a]

	All Subjects ($N = 94$)	Males ($N = 49$)	Females ($N = 45$)
Age (yr)	30.4 ± 0.9	30.5 ± 1.2	30.5 ± 1.3
	(20 –59)	(20 –59)	(20 –58)
Weight (kg)	75.5 ± 2.3	87.4 ± 3.3	62.5 ± 2.0**
	(43.2 –195.5)	(58.5 –195.5)	(43.2 –123.9)
Height (cm)	173.8 ± 1.0	180.9 ± 0.8	166.1 ± 0.9**
	(149.9 –194.3)	(171.4 –194.3)	(149.9 –179.1)
BMI (kg$\cdot m^{-2}$)	24.7 ± 0.6	26.6 ± 0.9	22.7 ± 0.8*
	(15.7 –55.9)	(19.0 –55.9)	(15.7 –50.9)
% Body fat	25.3 ± 0.9	24.2 ± 1.3	26.6 ± 1.3
	(7.3 –51.3)	(9.3 –46.4)	(7.3 –51.3)
Fat mass (kg)	19.9 ± 1.3	22.3 ± 2.1	17.3 ± 1.5
	(4.1 –90.7)	(7.0 –90.7)	(4.1 –63.6)
FFM (kg)	55.2 ± 1.4	64.8 ± 1.6	44.8 ± 0.9**
	(33.1 –104.8)	(47.0 –104.8)	(33.1 –58.3)
$\dot{V}O_{2max}$ (ml $O_2 \cdot kg^{-1}$ FFM$\cdot min^{-1}$)	53.94 ± 0.98	55.63 ± 1.08	52.10 ± 1.64
	(21.64 –76.56)	(31.22 –70.39)	(21.64 –76.56)

[a] Values are means ± SEM; ranges in parentheses; *t*-test, two-sample analyses assuming equal variances between male and female subjects; FFM, fat-free mass.
* $P < 0.002$; ** $P < 0.0001$.

TABLE 2. Energy expenditure variables measured.[a]

	All Subjects ($N = 94$)	Male Subjects ($N = 49$)	Female Subjects ($N = 45$)
24-h energy intake (MJ$\cdot d^{-1}$)	10.34 ± 0.30	11.77 ± 0.39	8.78 ± 0.31***
	(4.98 –16.88)	(7.33 –16.88)	(4.98 –13.80)
24-h energy expenditure (MJ$\cdot d^{-1}$)	9.86 ± 0.25	11.27 ± 0.28	8.32 ± 0.27***
	(6.40 –17.55)	(7.15 –17.55)	(6.40 –14.41)
24-h energy balance (MJ$\cdot d^{-1}$)	0.56 ± 0.19	0.63 ± 0.30	0.49 ± 0.22
	(−3.28 –4.57)	(−3.28 –4.57)	(−2.78 –4.31)
RMR (MJ$\cdot h^{-1}$)	7.12 ± 0.18	8.08 ± 0.22	5.92 ± 0.13***
	(4.72 –14.06)	(5.72 –14.06)	(4.72 –8.43)
SMR (MJ$\cdot d^{-1}$)	6.67 ± 0.14	7.60 ± 0.18	5.67 ± 0.10***
	(4.22 –13.18)	(5.74 –13.18)	(4.22 –7.41)
TEF (MJ$\cdot d^{-1}$)	1.42 ± 0.084	1.68 ± 0.09	1.13 ± 0.110***
	(−0.14 –3.49)	(0.27 –2.92)	(−0.01 –3.49)
EEact (MJ$\cdot d^{-1}$)	1.77 ± 0.11	1.99 ± 0.14	1.52 ± 0.17**
	(0.14 –5.13)	(0.66 –4.70)	(0.14 –5.13)
RMR RQ	0.808 ± 0.005	0.805 ± 0.007	0.811 ± 0.007
	(0.701 –0.972)	(0.701 –0.972)	(0.713 –0.930)
SMR RQ	0.825 ± 0.005	0.816 ± 0.006	0.834 ± 0.008*
	(0.702 –0.982)	(0.730 –0.969)	(0.702 –0.982)

[a] Values are means ± SEM; ranges in parentheses; *t*-test: two-sample analyses assuming equal variances between males and female subjects; TEF, thermic effect of food; EEact, energy expended during physical activity; RQ, respiratory quotient.
* $P < 0.04$; ** $P < 0.02$; *** $P < 0.0001$.

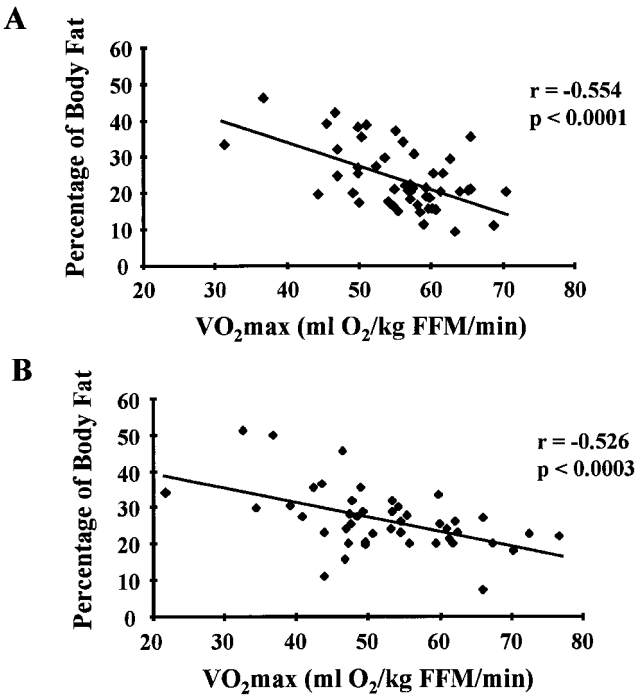

Figure 1—Relationships between level of aerobic fitness ($\dot{V}O_{2max}$) and percentage of body fat in 49 males subjects (A) and 45 female subjects (B).

TABLE 3. Correlation coefficients and probability values for relationships between $\dot{V}O_{2max}$ (ml $O_2 \cdot kg^{-1}$ fat-free mass·min^{-1}) and the measured physical and metabolic variables.

	All Subjects (N = 94)	Male Subjects (N = 49)	Female Subjects (N = 45)
Body weight (kg)	r = −0.203	r = −0.343	r = −0.494
	P = 0.050	P = 0.016	P < 0.0001
BMI (kg·m^{-2})	r = −0.307	r = −0.380	r = −0.428
	P = 0.003	P = 0.007	P = 0.003
% Body fat	r = −0.530	r = −0.554	r = −0.526
	P < 0.0001	P < 0.0001	P = 0.0003
Fat mass (kg)	r = −0.433	r = −0.511	r = −0.527
	P < 0.0001	P = 0.0002	P = 0.0002
Fat-free mass (kg)	r = 0.074	r = −0.049	r = −0.197
	P = 0.477	P = 0.737	P = 0.195
24-h energy intake (MJ·d^{-1})	r = 0.255	r = 0.119	r = 0.265
	P = 0.014	P = 0.420	P = 0.082
24-h energy expenditure (MJ·d^{-1})	r = 0.113	r = −0.208	r = 0.209
	P = 0.203	P = 0.152	P = 0.169
Fat oxidation (g·d^{-1})	r = −0.058	r = −0.397	r = 0.052
	P = 0.579	P = 0.005	P = 0.737
Protein oxidation (g·d^{-1})	r = 0.166	r = 0.130	r = 0.091
	P = 0.109	P = 0.372	P = 0.551
Carbohydrate oxidation (g·d^{-1})	r = 0.202	r = 0.143	r = 0.185
	P = 0.051	P = 0.326	P = 0.224
% Fat oxidation	r = −0.190	r = −0.274	r = −0.229
	P = 0.069	P = 0.059	P = 0.134
% Protein oxidation	r = 0.128	r = 0.260	r = 0.035
	P = 0.223	P = 0.074	P = 0.819
% Carbohydrate oxidation	r = 0.147	r = 0.138	r = 0.259
	P = 0.163	P = 0.349	P = 0.089
RMR (MJ·h^{-1})	r = 0.006	r = 0.049	r = 0.207
	P = 0.957	P = 0.745	P = 0.227
SMR (MJ·d^{-1})	r = 0.045	r = −0.170	r = −0.088
	P = 0.666	P = 0.244	P = 0.565

RMR, resting metabolic rate; SMR, sleeping metabolic rate.

When all subjects were considered, fat mass (r = 0.305, P = 0.003), FFM (r = 0.413, P < 0.0001) and body weight were significantly related to fat oxidation (Table 4). We conducted separate analyses in male and female subjects (Fig. 3). In male subjects, fat oxidation was significantly related with fat mass (r = 0.434, P = 0.002) but was not significantly correlated with FFM (r = 0.165, NS). In female subjects, fat oxidation was not significantly correlated with either fat mass (r = 0.108, NS) or FFM (r = 0.119, NS). In Figures 3C and 3D, there are individuals with a much higher fat mass than the average population (i.e., outliers). Removal of these data points did not significantly alter the relationship between fat mass and fat oxidation in male subjects (r = 0.369, P < 0.006) or female subjects (r = 0.229, P = 0.103). Fat oxidation was negatively correlated with 24-h energy balance, fat balance, and positively correlated with carbohydrate balance when subjects were analyzed as an entire group and also when separated by gender (Table 4).

There was a significant variation in energy balance among the subjects (−3.28 to 4.57 MJ·d^{-1}), despite our efforts to match energy intake with EE during the 24-h period measured in the whole-room calorimeter. Because we found a significant inverse relationship between fat oxidation and energy balance, we adjusted fat oxidation for energy balance and ran multiple regression analyses to examine the relationships between fat oxidation and $\dot{V}O_{2max}$ and between fat oxidation and body composition (FFM and fat mass). Multiple regression analyses of adjusted fat oxidation as a function of fat mass and FFM did not alter the significance of the relationship between fat oxidation and fat mass in men to a great extent (from multiple regression analysis, r = 0.450, P = 0.001). In addition, there remained no significant association between fat oxidation and body composition in women following a multiple regression analysis (data not shown).

DISCUSSION

In male subjects studied under sedentary conditions in a whole-room calorimeter, we found a positive correlation between body fat mass and 24-h fat oxidation and a negative correlation between level of aerobic fitness (as assessed by $\dot{V}O_{2max}$) and 24-h fat oxidation. Further, $\dot{V}O_{2max}$ was inversely related to body fat mass in this study population. This supports our hypothesis suggesting that the more aerobically fit male subjects would have a lower rate of daily fat oxidation than less physically fit male subjects under the sedentary (rest) conditions of this study. We therefore propose that a large portion of daily fat oxidation in subjects who engage in high levels of physical activity occurs during (or immediately after) the activity itself in order to maintain daily fat balance. In accordance with our hypothesis, 24-h fat oxidation determined during a day of limited physical

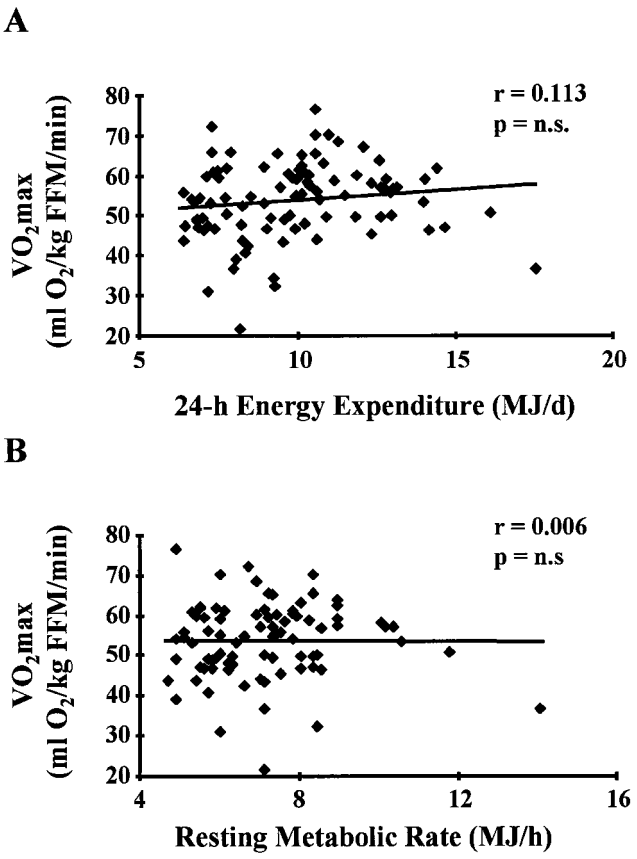

Figure 2—Relationships between level of aerobic fitness ($\dot{V}O_{2max}$) and 24-h energy expenditure (MJ·d^{-1}) (A) and RMR (MJ·h^{-1}) (B) in 94 subjects.

TABLE 4. Correlation coefficients and probability values for relationships between fat oxidation ($g \cdot d^{-1}$) and the measured physical and metabolic variables.

	All Subjects ($N = 94$)	Male Subjects ($N = 49$)	Female Subjects ($N = 45$)
Age (yr)	r = −0.003	r = 0.006	r = −0.030
	$P = 0.979$	$P = 0.967$	$P = 0.843$
Body weight (kg)	r = 0.416	r = 0.355	r = −0.033
	$P < 0.001$	$P = 0.012$	$P = 0.831$
% Body fat	r = 0.070	r = 0.404	r = −0.206
	$P = 0.505$	$P = 0.004$	$P = 0.174$
Fat mass (kg)	r = 0.305	r = 0.434	r = 0.108
	$P = 0.003$	$P = 0.002$	$P = 0.481$
Fat free mass (kg)	r = 0.413	r = 0.165	r = 0.119
	$P < 0.0001$	$P = 0.257$	$P = 0.435$
24-h energy intake ($MJ \cdot d^{-1}$)	r = 0.299	r = 0.016	r = 0.222
	$P = 0.004$	$P = 0.912$	$P = 0.148$
24-h energy balance ($MJ \cdot d^{-1}$)	r = −0.306	r = −0.320	r = −0.435
	$P = 0.003$	$P = 0.027$	$P = 0.003$
24-h fat balance ($MJ \cdot d^{-1}$)	r = −0.744	r = −0.779	r = −0.775
	$P < 0.0001$	$P < 0.0001$	$P < 0.001$
24-h carbohydrate balance ($MJ \cdot d^{-1}$)	r = 0.300	r = 0.429	r = 0.513
	$P < 0.0001$	$P = 0.002$	$P = 0.0004$
24-h protein balance ($MJ \cdot d^{-1}$)	r = −0.077	r = −0.036	r = 0.046
	$P = 0.467$	$P = 0.807$	$P = 0.769$

activity was positively correlated with fat mass in male subjects. It is important to note that the results were not different when $\dot{V}O_{2max}$ was expressed per unit of body weight instead of per unit of fat-free mass (data not shown).

There are several assumptions in our hypothesis. First, it assumes that there is a direct relationship between body fat mass and fat oxidation. Second, it assumes that regularly active subjects (those with a higher level of aerobic fitness) should have a lower fat oxidation under sedentary conditions than sedentary subjects. Although there is some support for the first assumption (1,22), others have not found this relationship (4,18). However, there are little data, collected over a whole day, related to the second assumption. The intent of the present study was to obtain data to further our understanding on the contribution of body fat mass to the regulation of daily fat oxidation.

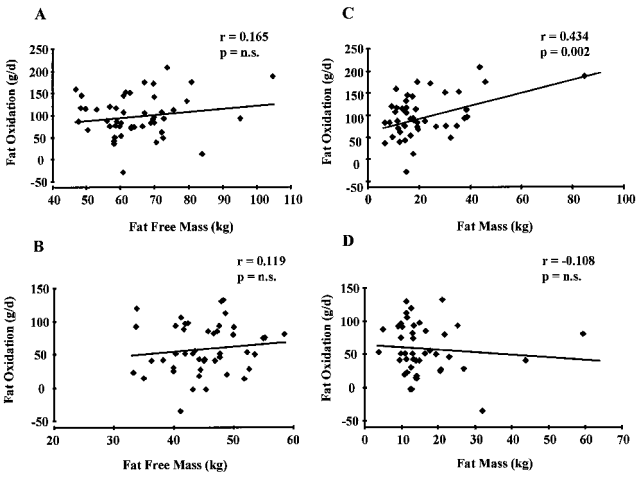

Figure 3—Relationships between fat oxidation ($g \cdot d^{-1}$) and fat free mass (kg) in 49 male subjects (A) and 45 female subjects (B) and fat mass (kg) in 49 male subjects (C) and 45 female subjects (D).

The physiological regulation of fat oxidation in humans has not been well characterized. Some studies support FFM as the major determinant of fat oxidation (4,18), whereas others suggest fat oxidation is more strongly correlated with fat mass than with FFM (1,22). However, because fat mass provides the substrate (i.e., fatty acids) for fat oxidation and because fatty acid release is proportional to the size of the adipose mass, it is not unreasonable to think that fat oxidation would be influenced more by the size of the body's adipose stores.

Along similar lines with the present findings, Schutz et al. (22) examined the relationships between body composition and fasting fat oxidation in 106 female subjects. The female subjects ranged in fat mass from 10 to 60 kg, and the correlation coefficient for the association between fat mass and fasting fat oxidation was $r = 0.56$, $P < 0.0001$. The range of body fat mass in the present study was similar. Astrup et al. (1) reported a significant correlation ($r = 0.61$, $P < 0.0001$) between fat mass and 24-h fat oxidation in 73 female subjects ranging in fat mass between 12 and 43 kg. In contrast, other studies in both male and female subjects failed to find a relationship between fat mass and fasting fat oxidation (4,16). In a study by Nagy and his colleagues (18), 427 male and 293 female subjects were examined. The fat mass in male subjects ranged from 0.3 to 50 kg, and a weak inverse relationship was found between fasting fat oxidation and fat mass ($r = -0.11$, $P < 0.05$). No relationship was found among the female subjects. When adjusted for RMR, the above relationship in male subjects was no longer significant.

It has been suggested that the contrasting findings in the regulation of fat oxidation in humans could partly be due to differences in the physical characteristics of the subjects studied, specifically, that populations differed with respect to, 1) the covariation of fat mass and FFM, and 2) the range of body composition explaining the greatest variance in fat oxidation (18). Although it is true that fat mass and FFM often covary, it is important to note that in the male subjects from the present study, 24-h fat oxidation was negatively correlated with $\dot{V}O_{2max}$ (expressed as mL $O_2 \cdot kg^{-1}$ body weight$\cdot min^{-1}$) after a multiple regression analysis with FFM and fat mass as covariates.

Data obtained with women did not fit our hypothesis. Despite finding a similar relationship between $\dot{V}O_{2max}$ and % body fat in female subjects as in the male population of this study, we found no relationship between $\dot{V}O_{2max}$ and fat oxidation in women. In female subjects, fat oxidation was not related either to body fat mass or to FFM. Our results in female subjects could represent a sampling error or could suggest that physical activity in female subjects may contribute to body weight regulation differently than in male subjects, i.e., governed by factors other than body composition, such as fatty acid supply (fat mass) or fatty acid oxidation capacity (FFM). Other studies have identified gender differences in how physical activity affects body weight regulation (13,26–28). Westerterp and Goran (27) analyzed all studies in which doubly labeled water has been used to assess energy expended in physical activity. They

found a negative relationship between body fatness and energy expended in physical activity in male subjects but no significant relationship in female subjects. In the present study, we used $\dot{V}O_{2max}$ as a marker of level of aerobic fitness, which has been extended to represent usual level of physical activity. It is possible that the relationship between energy expended in physical activity and $\dot{V}O_{2max}$ may differ in male and female subjects.

In general, athletes around the world eat diets containing a percentage of fat that is not different (and may be higher) than that consumed by the general U.S. public (8). Because EE and energy intake are higher in active versus sedentary individuals, athletes likely consume more fat on an absolute weight basis ($g \cdot d^{-1}$) than sedentary individuals. In accordance with our hypothesis, 24-h fat oxidation determined during a day of limited physical activity was positively correlated with fat mass in men. Alternatively, sedentary individuals who consume a typical Western diet may require a large fat mass in order to oxidize enough fat to balance fat intake. In the U.S., where dietary fat consumption is high, fat balance can be achieved in men at a low fat mass only if they engage in regular physical activity. If not, there is a high likelihood that body fat mass will have to be increased to achieve fat balance. It has been suggested that in situations where fat intake exceeds fat oxidation, the resulting increase in body fat mass will increase fatty acid release and increase total fat oxidation (1,22). Thus, becoming obese is one way to achieve fat balance when a high fat diet is consumed.

We found no relationship between $\dot{V}O_{2max}$ and either total 24-h EE, RMR, or SMR determined in adults who refrained from physical activity for at least 36 h before and during 24 h in a whole-room calorimeter. These results along with results of other studies (21,23) provide support that the effects of physical activity on EE are seen primarily during and immediately following the exercise bout. This raises an issue of whether physical activity performed more frequently (e.g., every day) would be more useful for body weight regulation than the same amount of exercise performed less frequently. If so, this could have important implications for physical activity guidelines to prevent obesity.

We should emphasize that we used $\dot{V}O_{2max}$ as an indicator of physical activity status. Because both physical activity patterns and genetic factors contribute to $\dot{V}O_{2max}$, it is possible that some of the subjects with high $\dot{V}O_{2max}$ may have been relatively inactive and some of the subjects with a low $\dot{V}O_{2max}$ may not have been sedentary. Should this have been a significant contributing factor to the conclusions reached in this study, then it is possible that the relationships observed may have been stronger if better assessment of actual level of physical activity had been obtained. Similarly, although we attempted to ensure that each subject in the whole-room calorimeter was in energy balance, this was not always the case. Although we believe that the degree of energy imbalance was relatively small and not likely to affect the results, the conclusions would have been stronger if we had achieved energy balance in all subjects. This is difficult to do in whole-room calorimeters where energy requirements are estimated (in this case from measured RMR plus an activity factor).

These results suggest that cessation of regular physical activity could create a situation favoring positive fat balance and weight gain. Although this could be prevented by an accompanying reduction in energy intake, it is not clear that free living humans have a good ability to adjust energy intake when total EE is low. The rising prevalence of obesity in our sedentary society supports this notion.

The results show in male subjects under sedentary conditions that 24-h fat oxidation is positively related to body fat mass and negatively to $\dot{V}O_{2max}$, adding support to our hypothesis that regularly active men may maintain a lower body fat mass because the contribution to fat oxidation from daily exercise counterbalances fat oxidation from body fat mass to ensure that daily fat balance is maintained. The lack of a relationship between $\dot{V}O_{2max}$ and 24-h EE suggests that the major effects of physical activity on EE and fat oxidation occur during and relatively quickly after a bout of exercise. Further, these data also suggest that cessation of regular exercise should be associated with a high risk of positive fat balance and weight gain.

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