Energy expenditure (EE) was measured at specific steady-state work rates to determine if body fat percentage or gender was associated with exercise EE, substrate oxidation, or work efficiency. Body fat percentage (leaner vs. fatter men, 9–15% vs. 20–25% fat; leaner vs. fatter women, 16–24% vs. 32–48% fat) was not related to work efficiency or submaximal EE. Fatness affected substrate oxidation in men but not in women. Compared to fatter men, leaner men had higher fat oxidation (6.7 ± 1.6 vs. 1.4 ± 2.0 mg · kg fat-free mass $^{-1}$ · min$^{-1}$; p < .01) and lower carbohydrate oxidation (26.6 ± 4.2 vs. 39.3 ± 5.0 mg · kg FFM$^{-1}$ · min$^{-1}$; p < .01) at 60% $\dot{V}O_{2\text{max}}$. When men and women of similar fatness and relative aerobic capacity were compared, men had higher EE measured as kilojoules per minute but similar rates of EE and substrate oxidation per kilogram of FFM at 40–60% $\dot{V}O_{2\text{max}}$. It was concluded that body FFM, not fatness, is a determinant of exercise EE, whereas fatness is associated with differences in exercise substrate oxidation in men. Along with aerobic fitness, gender and fatness should be considered in future studies of exercise substrate oxidation.

Key Words: cycle ergometry, carbohydrate oxidation, fat oxidation, gender, energy utilization

It is well known that body fat-free mass (FFM) is a chief determinant of metabolic rate (23), but little is known about the relationship between fat mass and energy expenditure and utilization. According to Flatt (9), enlargement of the fat mass increases the availability of free fatty acids as metabolic fuel and promotes fat oxidation. However, in one study conducted in a respiratory chamber under conditions of low physical activity, percentage body fat was related to fat oxidation (22), and in another study it was not (21). Further, the relationship between fat mass and energy utilization during physically active periods is not well defined in humans. More studies in this area are needed, particularly since Flatt (10) proposed that...
Exercise can be interchanged with enlargement of fat mass to bring about increased fat oxidation and to impact daily fat balance and body weight maintenance.

When studying the effect of body fat on energy expenditure, researchers must consider the inherent differences in body fat content between men and women. Studies comparing exercise energy utilization of men and women have yielded inconsistent results. Compared to men, women utilized a larger proportion of fat for energy production in some studies (3, 26) but not in others (6). In these same studies, women’s absolute rates of fat oxidation, measured in grams per minute, were lower than (6), higher than (26), or similar (3) to those of men. Several investigators have suggested that body fat differences between men and women contribute to differences in metabolic responses to exercise (13, 16, 25), although systematic studies are lacking.

Efficiency of work performance is another aspect of exercise energetics that may be influenced by body composition. In extremely and moderately obese individuals (2, 7, 11), mechanical efficiency was low during non-weight-bearing exercise on a cycle ergometer and increased after significant weight loss. In other studies, modest weight changes in normal-weight individuals (14, 28) and moderately overweight individuals (20) did not alter exercise efficiency during cycling. Thus, the point at which body weight or body composition begins to affect exercise efficiency is not clear.

The objective of our study was to determine if body fat percentage was associated with exercise energy expenditure, substrate oxidation rates, or work efficiency. We determined energy expenditure at specific steady-state work rates during non-weight-bearing exercise on a cycle ergometer to estimate mechanical efficiency and energy utilization during submaximal exercise. To distinguish between body fatness and gender effects on exercise energetics, we tested for within-gender body fat effects and compared genders after matching subjects by body fat percentage.

Subjects and Methods

Subjects

To be included in the study, subjects had to be healthy, had to be under 40 years old, and had to weigh no more than 140% of desirable weight for height, using the 1980 Metropolitan Life Insurance Standards. Initially, body composition (by hydrostatic weighing) and maximal aerobic capacity were determined for 80 subjects, and from this pool, subjects were selected as follows. To examine the effect of body fat percentage on exercise energy expenditure and substrate oxidation, fatter men (body fat ≥20%, n = 8) were compared to leaner men (body fat <20%, n = 8), and fatter women (body fat ≥30%, n = 8) were compared to leaner women (body fat <30%, n = 8) (Table 1). In addition, within gender, these subjects were paired by similar aerobic capacity (within-pair maximal oxygen consumption relative to FFM matched within 3 ml · min⁻¹) to minimize the possible confounding effect of aerobic capacity on energy utilization. To examine the effect of gender on exercise energy expenditure and substrate oxidation, different sets of men (n = 10) and women (n = 10) were compared (Table 2). The men and women were paired by similar body fatness (within-pair body fat percentage matched within 3%) and aerobic capacity (within-pair maximal oxygen consumption relative to FFM matched within...
Table 1  Physical Characteristics of Subjects Grouped by Body Fatness ($n = 8$ for Each Group)

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th>Women</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaner</td>
<td>Fatter</td>
<td>Leaner</td>
<td>Fatter</td>
</tr>
<tr>
<td>M</td>
<td>SEM</td>
<td>M</td>
<td>SEM</td>
<td>M</td>
</tr>
<tr>
<td>Age (years)</td>
<td>29$^a$</td>
<td>1</td>
<td>34$^a$</td>
<td>1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.1$^a$</td>
<td>2.2</td>
<td>80.6$^a$</td>
<td>3.1</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>12.4$^c$</td>
<td>0.8</td>
<td>22.1$^c$</td>
<td>0.6</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>59.6</td>
<td>1.9</td>
<td>62.7</td>
<td>2.2</td>
</tr>
<tr>
<td>$\dot{V}O_2$max (L · min$^{-1}$)</td>
<td>3.67</td>
<td>0.12</td>
<td>3.85</td>
<td>0.13</td>
</tr>
<tr>
<td>(ml · kg FFM$^{-1}$ · min$^{-1}$)</td>
<td>61.61</td>
<td>1.41</td>
<td>61.54</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Note. Within each gender, means sharing common superscripts are significantly different: $^a_p \leq .05$, $^b_p \leq .01$, $^c_p \leq .001$.

Table 2  Physical Characteristics of Subjects Grouped by Gender ($n = 10$ for Each Group)

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th>Women</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SEM</td>
<td>M</td>
<td>SEM</td>
</tr>
<tr>
<td>Age (years)</td>
<td>30</td>
<td>1</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.2$^a$</td>
<td>3.0</td>
<td>53.1$^a$</td>
<td>1.6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>19.3</td>
<td>1.0</td>
<td>19.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>63.8$^a$</td>
<td>2.0</td>
<td>42.7$^a$</td>
<td>3.4</td>
</tr>
<tr>
<td>$\dot{V}O_2$max (L · min$^{-1}$)</td>
<td>3.88$^a$</td>
<td>0.28</td>
<td>2.59$^a$</td>
<td>0.20</td>
</tr>
<tr>
<td>(ml · kg FFM$^{-1}$ · min$^{-1}$)</td>
<td>60.93</td>
<td>4.55</td>
<td>60.54</td>
<td>4.41</td>
</tr>
</tbody>
</table>

Note. Means sharing common superscripts are significantly different: $^a_p < .001$.

3 ml · min$^{-1}$). Participation was by informed consent. The study protocol was approved by the Human Subject Committees of the U.S. Department of Agriculture and Letterman Army Medical Center.

**Experimental Protocol and Measurements**

For each subject, on the first test day body composition and $\dot{V}O_2$max were measured. On the second test day, which was scheduled after at least 1 day of rest following the $\dot{V}O_2$max test, pre-exercise resting metabolic rate at rest and exercise energy expenditure and work efficiency were measured. This rest and exercise protocol was conducted between 8 and 11 a.m., with subjects in the postabsorptive state. Prior to both test days, subjects were instructed to maintain their usual diets and refrain from vigorous activity for the day preceding the tests.
To measure body composition, body density was determined by hydrostatic weighing (1). Concurrently, residual lung volume was determined by oxygen dilution (29). The Siri equation was used to calculate body fat percentage from body density values (24).

Maximal oxygen consumption was measured using a Monarch mechanically braked cycle ergometer, beginning with unloaded cycling at 60 rpm and increasing the resistance by 30 W (0.5 kp) every 2 min. Subjects continued pedaling to the point of exhaustion. Volume of expired air, oxygen consumption (\( \dot{V}O_2 \)), and carbon dioxide production (\( \dot{V}CO_2 \)) were measured continuously using an automated system (Horizon Metabolic Measurement Cart, SensorMedics, Anaheim, CA). To collect respiratory gases, each subject wore a noseclip and breathed through a mouthpiece attached to a Hans Rudolph low-resistance, nonrebreathing valve. Heart rate was monitored continuously by ECG.

Pre-exercise resting metabolic rate was calculated from respiratory gas measurements collected for 10–15 min while the subject sat in a comfortable chair, using the same automated system as described previously. Exercise energy expenditure and work efficiency were measured using a cycle ergometer. This form of exercise was chosen to minimize the possible confounding effect of body weight on exercise energy expenditure. The test protocol began with 5 min of unloaded cycling at 60 rpm followed by 5 min of rest. Work rates were progressively increased to 30, 60, 90, and 120 W. For the men, the test was extended to 150 W. Each of these loaded cycling stages was 5 min in duration at a pedaling speed of 60 rpm. Subjects rested for 5 min between each stage. Respiratory gases were collected continuously, but only data from the final 2 min of work performance at each stage were used to calculate energy expenditure, respiratory exchange ratio (RER), and mechanical efficiency.

To measure urinary nitrogen output, subjects were instructed to urinate to empty their bladders immediately before the start of testing. This time (marking the beginning of the urine collection period) was recorded. Following completion of the cycling protocol, the subjects provided another urine sample, and the time was again recorded. The nitrogen content of this urine sample was determined by the Kjeldahl method (4), and the urinary nitrogen excretion rate during the test period was used in the calculations of energy expenditure and substrate oxidation rates.

Respiratory gas measurements and urinary nitrogen excretion rates were used to calculate energy expenditure at rest and at each stage of work using the equation of Consolazio (5):

\[
\text{Total energy expenditure} = (3.78 \times \dot{V}O_2) + (1.16 \times \dot{V}CO_2) - (2.98 \times \text{urinary nitrogen})
\]

This equation yields energy expenditure rates in calories per minute (kcal \( \cdot \) min\(^{-1}\)) when \( \dot{V}O_2 \) and \( \dot{V}CO_2 \) units are in liters per minute (L \( \cdot \) min\(^{-1}\)) and urinary nitrogen units are in grams per minute (g \( \cdot \) min\(^{-1}\)). Kilocalories were converted to kilojoules using the constant 1 kJ = 0.239 kcal.

Using respiratory gas exchange data that were collected at each stage of work, we used linear regression analyses of \( \dot{V}O_2 \) and \( \dot{V}CO_2 \) as a function of relative exercise intensity to estimate \( \dot{V}O_2 \) and \( \dot{V}CO_2 \) for the specific exercise intensities of 30, 40, 50, and 60% of \( \dot{V}O_2 \)max. The estimated values for \( \dot{V}O_2 \) and \( \dot{V}CO_2 \), along with the value obtained for urinary nitrogen, were used in Equation 1 to estimate energy expenditure at 30, 40, 50, and 60% of \( \dot{V}O_2 \)max. Fat and carbohydrate oxidation...
rates, in grams per minute (g · min⁻¹), were also calculated for these submaximal intensities using other Consolazio equations (5):

\[
\text{Fat oxidation rate} = (1.689 \times \dot{V}O_2) - (1.689 \times \dot{V}CO_2) - (1.943 \times \text{urinary nitrogen}) \tag{2}
\]

\[
\text{Carbohydrate oxidation rate} = (4.115 \times \dot{V}CO_2) - (2.909 \times \dot{V}O_2) - (2.539 \times \text{urinary nitrogen}) \tag{3}
\]

In this study, mechanical efficiency was defined as work efficiency (12), that is, work accomplished divided by energy expended above that expended while cycling at 0 W. Delta efficiency was also calculated as the ratio between the change in work accomplished and the change in energy expended above the previous work rate, multiplied by 100.

**Statistical Analysis**

All descriptive data for groups of subjects are expressed as mean ± SEM. The general linear model procedure of the SAS Institute (Cary, NC) was used for analysis of variance to determine if body fat percentage or gender affected energy expenditure, work efficiency, or substrate oxidation rates for each level of work or exercise intensity. Due to inherent differences in body fatness of men and women, leaner and fatter subjects were compared by gender. A comparison to test for gender effect was done with a different set of men and women who were matched by body fat percentage. The model adjusted for the subject pairs who were also matched by relative aerobic capacity. The probability level of significance was set at .05.

**Results**

The fatter men (20–25% body fat) weighed more than the leaner men (9–15% body fat) but had similar FFM (Table 1). The fatter women (32–48% body fat) not only weighed more than the leaner women (16–24% body fat) but also had significantly more FFM (Table 1). Mean values for \( \dot{V}O_2\max \), relative to FFM, were similar for the leaner and fatter men, as were the mean values for the leaner and fatter women (Table 1).

For the gender comparison, men weighed more than women and had higher absolute values for FFM and fat mass, but the body fat percentage and \( \dot{V}O_2\max \) values relative to FFM were similar between the men and women (Table 2).

Body fatness was not associated with energy expenditure at rest or at any of the fixed cycling work rates in men (Figure 1, left graph) or in women (Figure 1, middle graph). When men and women matched for body fat percentage and relative aerobic capacity were compared, women had higher energy expenditures at rest and during cycling, with the gender difference increasing as the work rate increased (Figure 1, right graph).

Exercise intensities (% \( \dot{V}O_2\max \)) at the fixed work rates were similar in leaner and fatter men and in leaner and fatter women (Table 3). The gender comparison revealed that men were working at a lower percentage of \( \dot{V}O_2\max \) than women throughout the work rate range (Table 3).

For men, when energy expenditure was estimated for the relative submaximal exercise intensities of 30, 40, 50, and 60% of \( \dot{V}O_2\max \), there was no effect of body fatness on energy expended (measured either as kJ · min⁻¹ or kJ · kg FFM⁻¹ · min⁻¹) (Figure 2, left graph).
Figure 1 — Rates of energy expenditure at rest and during work. The effect of body fat percentage was tested in men (left graph) and women (middle graph). Each bar represents mean ± SEM (n = 8). The effect of gender was tested in separate groups of men and women (right graph). Each bar represents mean ± SEM (n = 10). Significant differences: *p ≤ .05, **p ≤ .01, ***p ≤ .001.
Figure 2 — Estimated rates of energy expenditure at submaximal exercise intensities. The effect of body fat percentage was tested in men (left) and women (middle). Each point represents mean ± SEM (n = 8). The effect of gender was tested in separate groups of men and women matched for body fatness (right). Each point represents mean ± SEM (n = 10). Insert graphs have energy expenditure expressed relative to fat-free mass. Some error bars are not visible because the SEM is so small. Significant differences: *p ≤ .05, **p ≤ .001.
Table 3  Exercise Intensity (% \(\dot{V}O_2\text{max}\)) at Fixed Work Rates for Men and Women

<table>
<thead>
<tr>
<th>Work rate</th>
<th>30 W</th>
<th>60 W</th>
<th>90 W</th>
<th>120 W</th>
<th>150 W</th>
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<tr>
<td></td>
<td>M</td>
<td>SEM</td>
<td>M</td>
<td>SEM</td>
<td>M</td>
</tr>
<tr>
<td><strong>Men—body fat group comparison</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaner ((n = 8))</td>
<td>20</td>
<td>1</td>
<td>28</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>Fatter ((n = 8))</td>
<td>20</td>
<td>1</td>
<td>27</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td><strong>Women—body fat group comparison</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaner ((n = 8))</td>
<td>27</td>
<td>2</td>
<td>40</td>
<td>2</td>
<td>54</td>
</tr>
<tr>
<td>Fatter ((n = 8))</td>
<td>29</td>
<td>2</td>
<td>42</td>
<td>4</td>
<td>57</td>
</tr>
<tr>
<td><strong>Gender comparison</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men ((n = 10))</td>
<td>20</td>
<td>1</td>
<td>28</td>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>Women ((n = 10))</td>
<td>25</td>
<td>2</td>
<td>37</td>
<td>2</td>
<td>50</td>
</tr>
</tbody>
</table>

Note. Women did not complete the 150 W work rate. For the gender comparison, means in vertical columns sharing the same superscript are significantly different: \(^a p < .01, ^b p < .001\).

Although the fatter women had slightly higher absolute rates of energy expenditure than the leaner women, this difference was eliminated when energy expenditure was expressed relative to FFM (Figure 2, middle graph). Also, the marked gender effect on absolute rates of energy expenditure was eliminated if energy expenditure was expressed relative to FFM (Figure 2, right graph).

At rest, mean RER was similar among the body fatness groups: 0.80 ± 0.03, 0.81 ± 0.02, 0.79 ± 0.03, and 0.78 ± 0.06 for leaner men, fatter men, leaner women, and fatter women, respectively. These RER values corresponded with resting fat oxidation rates of 1.12 ± 0.31, 0.91 ± 0.28, 1.25 ± 0.40, and 1.45 ± 0.50 mg · kg FFM\(^{-1} \cdot \text{min}^{-1}\), respectively. The men and women matched for body fat percentage also had similar resting RERs: 0.82 ± 0.03 and 0.80 ± 0.02, corresponding to resting fat oxidation rates of 0.85 ± 0.23 and 1.19 ± 0.30 mg · kg FFM\(^{-1} \cdot \text{min}^{-1}\), respectively. Mean RER increased as work rate increased for all subjects. At 120 W, leaner men had a significantly lower RER (0.87 ± 0.03) than fatter men (0.93 ± 0.03) \((p < .01)\).

Substrate oxidation rates were estimated only at submaximal exercise intensities to 60% \(\dot{V}O_2\text{max}\) rather than at specific work rates because several women were working above their anaerobic threshold at 120 W. Fat oxidation rates at 40, 50, and 60% \(\dot{V}O_2\text{max}\) differed for the leaner and fatter men. The fat oxidation rate of leaner men tended to increase as exercise intensity increased, whereas that of fatter men tended to decrease (Figure 3, left graph). Although carbohydrate oxidation increased with increasing exercise intensity, leaner men had significantly lower carbohydrate oxidation rates compared to fatter men (Figure 3, left graph). In contrast to men, body fat percentage of women was not associated with fat or carbohydrate oxidation rate (Figure 3, middle graph). For the men and women who were matched for body fatness, carbohydrate oxidation rates tended to be higher and fat oxidation rates tended to be lower for the men, but the gender difference was only significant at 30% \(\dot{V}O_2\text{max}\) (Figure 3, right graph).
Figure 3 — Substrate oxidation rates at submaximal exercise intensities. Carbohydrate and fat oxidation rates are depicted on each graph for men (left), women (middle), and men and women matched for body fatness (right). Each symbol represents mean ± SEM (open symbols = carbohydrate oxidation, solid symbols = fat oxidation). Significant differences: *p ≤ .05, **p ≤ .01.
Figure 4 — Work efficiency at fixed work rates in groups of men (left), women (middle), and men and women matched for body fatness (right). Each point represents mean ± SEM.
Work efficiency was not related to body fat percentage or gender (Figure 4). Delta efficiency from 30 to 60 W, 60 to 90 W, and 90 to 120 W did not differ between leaner or fatter subjects or between genders.

**Discussion**

According to the body composition standards of Lohman (17), the fatter men in our study would be considered “fat” and the leaner men would be considered “optimal” with regard to body fat percentage. A comparison of these men revealed that body fat percentage did not affect submaximal exercise energy expenditure. However, fat oxidation was higher and carbohydrate oxidation was lower in leaner men compared to fatter men at exercise intensities of 40–60% VO$_2$max. Because the leaner and fatter men were matched for maximal aerobic capacity, this effect of body fat percentage on substrate oxidation rates was independent of physical fitness. Recently, Harms et al. (15) reported that men with low body fat utilized more fat during 20 min of submaximal (70% VO$_2$max) treadmill exercise and during the first 30 min of recovery compared to men with high body fat. These authors suggested that the differences in fat utilization were likely a result of increased lipoprotein lipase and/or lipolysis in the men with low body fat. Despite reports that men’s adipose tissue is more responsive to adrenergic stimulation than that of women (8, 27), adipose cell lipolytic responsiveness has an important genetic component (18), and this trait may be associated with or influential in determining degree of body fatness. Thus, the leaner men may have displayed increased fat utilization because of the inherent lipolytic properties of their adipocytes and may be leaner as a result of this.

In contrast, body fat percentage of the women was not associated with substrate oxidation rates, even though the difference in body fat percentage between the leaner and fatter women was greater than the difference between the men’s groups. The fatter women in this study would be considered “obese” by Lohman’s standards. Also, the fatter women had considerably more FFM than their leaner counterparts, a factor that resulted in higher absolute exercise energy expenditure. When exercise energy expenditure was expressed relative to kilograms of FFM, there were no energy expenditure differences between leaner and fatter women.

In this study, by matching men and women with similar body fat percentages and maximal aerobic capacities relative to FFM, we found that women expended more energy (expressed as kJ · kg FFM$^{-1}$ · min$^{-1}$) than did men at all work rates. This resulted because the women were exercising at higher intensities at all work rates, and when energy expenditure was estimated at the same relative exercise intensities, the difference between men and women disappeared. However, because the men had more FFM, their absolute energy expended per minute was greater throughout the submaximal intensity range. On average, the men would expend 485 kJ (115 kcal) more than the women for a 30-min workout at 60% of VO$_2$max. These data illustrate the degree to which body FFM affects exercise energy output, and for individuals exercising daily, the difference could have a substantial impact on energy balance.

The increased exercise EE observed in men appeared to be a function of greater carbohydrate oxidation. In men and women of similar body fat percentage (ranging from 15 to 25%), submaximal fat utilization tended to be greater in women than men, but the differences were only significant at 30% VO$_2$max. At 40–60% VO$_2$max, the differences were not significant due to the large intersubject variation in RER. Tarnopolsky et al. (26) found that women running at 65% VO$_2$max utilized
more fat per minute and as a percentage of total energy compared to men running at the same relative intensity. However, Blatchford et al. (3) found that women utilized a higher proportion of energy from fat, but fat oxidation rate (g·min⁻¹) was similar to that of men during exercise at 35% VO₂max. Our findings are more similar to those of Blatchford et al. (3), but a direct comparison of studies is problematic because other variables that can influence substrate oxidation during exercise, such as aerobic capacity, antecedent diet, and overall state of energy balance, varied among studies. Since we did not control subjects’ diets on the days preceding testing, we cannot rule out the possibility that group differences or trends in substrate oxidation might be due to group differences in energy intake level or diet composition, although the similar resting RER values of the groups suggest that there were no dietary differences.

Our findings indicate that in addition to FFM, body fat percentage is another variable that is related to exercise substrate oxidation in men. The group results can be used to illustrate the varying degree to which exercise substrate oxidation rates might impact body weight maintenance. Flatt (9, 10) proposed that body fat content is maintained at a set point that can be altered by circumstantial conditions such as regular exercise. Second, maintenance of body weight and composition requires that fat oxidation rates are commensurate with dietary fat intake. Thus, by increasing fat oxidation rate during the exercise period and also by altering postexercise metabolism, exercise can impact fat balance by lowering 24-hr respiratory quotient. If dietary fat intake does not change, the potential result could be a reduction in body fat mass.

Although our study did not address postexercise metabolism, our data indicate that fat oxidation rate increased approximately fourfold from rest to exercise at 30% VO₂max in all groups. Assuming that the resting fat oxidation rate represents the 24-hr rate during an inactive day, 30 min of exercise at 30% VO₂max could increase 24-hr fat oxidation by 6–7%. Most likely, this would represent the minimum impact that could be expected from a 30-min session at this intensity, because it is known that RER decreases during sustained exercise as fuel utilization shifts to increase the proportion of fat oxidized (19). Of course, with longer exercise duration, the 24-hr fat oxidation rate could be increased more. As a group, the leaner men were unique in that they oxidized more fat at higher exercise intensities. Their fat oxidation rate increased sixfold from rest to exercise at 60% VO₂max. For this group, 30 min of exercise at 60% VO₂max could increase 24-hr fat oxidation by at least 10%, whereas the same workout for the other groups would increase 24-hr fat oxidation by only 1–5%. Furthermore, the leaner men’s maximal fat oxidation rate occurred at 60% VO₂max, coinciding with a higher rate of energy expenditure. All others had maximal fat oxidation rate at 30% VO₂max, coinciding with a lower rate of energy expenditure. As a result, only the leaner men have the option to exercise at a submaximal intensity that maximizes both fat oxidation and energy expenditure. Thus, by incorporating habitual exercise into their daily routine, the leaner men appear to have a metabolic advantage for maintaining fat balance, energy balance, and body weight. For the other groups, it appears that regular exercise could exert only a minor effect on 24-hr fat oxidation rate and fat balance.

Neither body fatness nor gender affected work efficiency during non-weight-bearing exercise. The lack of effect of body fatness on work efficiency agrees with the findings of Hanson (14), who reported that a weight gain of 15–19% did not affect gross efficiency; this finding also agrees with the findings of Poole and Henson, (20) who reported that a weight loss of 3–8% did not change
work efficiency. On the other hand, Freyschuss and Melcher (11) presented the most striking evidence that obesity lowered exercise efficiency. They did not measure body composition, but their subjects were extremely overweight (approximately 100% above desirable weight). The relative weight of our subjects ranged from 81 to 106% of desirable for the leaner groups and 107 to 138% for the fatter groups. Thus, it appears that individuals must be considerably more overweight than our subjects before body fatness affects work efficiency.

In conclusion, body fatness was not a significant determinant of exercise EE, but body fat percentage was associated with exercise substrate utilization in men such that the leaner men had higher fat oxidation rates during exercise. More studies examining exercise energy utilization should be conducted to further our understanding of the association between body fatness and exercise substrate oxidation. These studies could examine both environmental and genetic influences and define the specific biochemical and endocrine mechanisms that underlie the differences in exercise substrate utilization.

References


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