Effect of habitual exercise on daily energy expenditure and metabolic rate during standardized activity\(^1\,\,^3\)

Tracy J Horton and Catherine A Geissler

ABSTRACT To assess whether long-term habitual exercise affects energy expenditure even on a nontraining day, 24-h energy expenditure (24-h EE) and metabolic rate of sedentary, moderately active, and highly active males \((n = 10\) per matched group), were measured in a room respirometer on two separate occasions: sedentary and standardized mild-exercise protocols. Twenty-four-hour EE was greatest in the highly active group, second highest in the moderately active group, and lowest in the sedentary group on both experimental days (sedentary day: 9908 ± 344, 9328 ± 357, and 8669 ± 227 kJ/d; exercise day: 11915 ± 395, 11609 ± 328, and 11063 ± 370 kJ/d, respectively). Differences were significant between the 24-h EE \((P < 0.01)\), waking \((P < 0.03)\), and sleeping metabolic rate \((P < 0.01)\) of the highly active group compared with the sedentary group. However, when expressed per unit lean body mass (LBM), group values on both experimental days were not significantly different. Therefore, we found no evidence that habitual exercise, at a high or moderate level, leads to a significant prolonged stimulation of metabolic rate per unit active tissue. However, the increased LBM associated with exercise does increase daily energy expenditure by 8–14%. Am J Clin Nutr 1994;59:13–9.

KEY WORDS Daily energy expenditure, metabolic rate, habitual exercise, humans

Introduction

The prolonged effects of physical exercise on human metabolic rate have received much attention in light of its potential effect on energy balance. Promotion of regular exercise as a means of stimulating metabolism has been common among health and fitness enthusiasts with the implication that this effect is long-term \((1)\). Apart from the energy cost of the physical activity itself, there is an elevation of metabolic rate for a limited time period postexercise \((2)\). However, it appears that exercise must be of a high intensity and for a long duration before a significant and prolonged elevation in metabolic rate is observed beyond several hours \((3–5)\). In addition, an effect of regular exercise on resting metabolism and the metabolic response to thermogenic stimulants has been postulated.

Certain studies have reported that highly trained athletes have a greater resting metabolic rate (RMR) per unit lean body mass (LBM) compared with their sedentary counterparts \((6–10)\), although others have not been able to confirm this finding \((11)\). In contrast, it has been reported that the thermic response to feeding is reduced in trained compared with untrained individuals \((7, 9, 12–14)\). In general, the above studies suggest that regular exercise may result in a prolonged effect on energy metabolism. This effect could either be a direct result of the carryover effect from the previous exercise session or possibly a result of an alteration in the long-term metabolic activity of body tissues. To assess the impact of regular exercise habits on long-term energy balance, it is more relevant to measure energy expenditure (EE) over time periods greater than a few hours and in a situation more representative of daily life. However, determinations of daily EE in trained and untrained subjects have only been made under sedentary conditions in a room respirometer and under these conditions no group differences were found \((15)\). The impact of more moderate levels of activity on daily EE have not been addressed and there is some indication, from acute studies, that moderately trained subjects may differ metabolically from highly trained and untrained individuals \((7, 10, 14)\).

We therefore assessed whether or not long-term habitual exercise patterns lead to an elevation in metabolic rate, and/or daily EE, in sedentary, moderately active, and highly active males. Assessing EE under two conditions—sedentary and active (non-training)—enabled us to compare results for a more typical day with those of an atypical sedentary day.

Subjects and methods

Subject selection

Subjects were selected from members of staff and students attending King’s College, University of London; members of Richmond Canoe Club, Surrey, UK; and members of the general public. All subjects were healthy and no individual was suffering from any type of metabolic disorder or taking any form of medication during the course of the study. Subjects were classified as sedentary, moderately active, and highly active on the basis of their habitual exercise patterns. To assess the level of habitual activity, voluntary exercise of a moderate to high intensity \((16)\)

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was considered, because the majority of subjects had sedentary
work patterns except for three subjects belonging to the highly
active group. Walking was only included as exercise if it was for
a prolonged time or of a high intensity, eg, hiking. The sedentary
group was involved in no or little regular exercise on a weekly
basis; the moderately active group averaged 6 h activity per
week, and the highly active group comprised competitive ama-
teur sportsmen training on average 12–16 h/wk. These were typ-
ical patterns of activity for the preceding year at least. Subjects
were matched for height (±5 cm), weight (±3 kg), and age (±5
y) with 10 subjects in each group.

Study design

The EE of each subject was measured for 24 h in a room
respirometer on two occasions: sedentary day and exercise day,
on which standardized cycling and stepping exercises were per-
formed. The sequence in which the subjects completed the 2 d
was randomized in a crossover design to avoid any possible ef-
effect of order on the final results. During both sessions the subjects
consumed their habitual energy intake. In addition, a subgroup
of the highly trained subjects repeated the sedentary protocol
without exercise training the day before. The experimental pro-
tocol was approved by the Ethical Committee for Human Ex-
perimentation, King’s College, University of London. All pro-
cedures were fully explained to each individual and they gave
their informed consent to participate.

Methods

Height and weight were measured in the morning to the nearest
0.5 cm and 0.2 kg, respectively. Weight was taken with subjects
wearing light clothing and after they had voided. Body fat was
estimated from skinfold-thickness measurements as described by
Durnin and Womersley (17) and LBM was calculated from body
weight and percentage body fat.

Each volunteer completed a 7-d weighed diet diary to assess
his habitual energy consumption and macronutrient intake. All
food and drink were weighed on digital scales (Soehnle Digimail
8000/8001; Abinghurst Ltd, Northampton, UK) and detailed in-
structions were given on how to complete the diet record. Food
diaries were checked during and at the end of the period for
accurate completion and results analyzed by using McCance and
Widdowson’s food-composition tables (18) and its second sup-
plement, Immigrant Foods (19), and additional dietary-compo-
sition data (20).

Specific exercise was not carried out by any of the sedentary
group on the days before the EE measurements. Five of the mod-
erately active subjects undertook some form of light exercise
whereas all subjects in the highly active group trained on the
days before the measurements of daily EE. Exercise did not occur
later than 1730 for any subject. The diet and exercise patterns
preceding the first experimental run were repeated the day before
the second EE measurement. To verify these patterns, partici-
pants completed unweighed food inventories and activity diaries.
No food or beverages, except water, were taken after 2100 on
the evening before each experiment.

An open-circuit room respirometer was used to measure the
daily EE of subjects. This system was described in detail previ-
ously (21) and has an error of <3%. Volunteers arrived fasted
and nonexercised at the college between 0800 and 0900. After
resting for 30 min subjects entered the room respirometer. Each
individual completed two separate 24-h EE measurements: 1) the
sedentary day—subjects spent the vast majority of their time in
sedentary activities with small amounts of time spent standing
and/or putting to perform personal toilet and other necessities.
2) exercise day—activities were, for the most part, the same as
those on the sedentary day. In addition there were three sessions of
exercise: in the morning, early afternoon, and early evening.
Each session consisted of 15 min of step exercises (stepping on
and off a 22.5-cm high wooden box at a rate of 24 steps/min)
and 15 min cycling (impedence of 7%, 6.0–6.5 km/h). The in-
tensity of the exercise was moderate, equivalent to 5.5–6.5
METS/min (where 1 MET is equivalent to the oxygen consump-
tion at rest, =3.5 mL: kg−1: min−1). The performance of the ex-
ercises was timed by using a stop clock. A standardized, nontraining
level of activity was used because this was acceptable
to all subjects and allowed comparison of results between
subjects.

To assess the direct effect of exercise training on EE the fol-
lowing day, five members of the highly active group were able to
repeat the sedentary protocol without exercise training the day before. In these subjects results were obtained for 2 sedentary
days: the posttraining sedentary day and the postnontraining seden-
tary day.

Activity diaries were completed by subjects while inside the
room respirometer. The day was broken down into hourly inter-
vals and further subdivided into 5-min blocks. A record of type
of activity performed and body position maintained were re-
corded to the nearest 5 min throughout each EE measurement.

The quantity of food provided on each experimental day was
calculated to give an energy intake (EI) equal to each subjects
habitual EI as assessed from their dietary record. All food was
prepared in the laboratory kitchen and accurately weighed on
digital scales (model EB 3000; Salter Electroscale, A&B Scien-
tific, West Sussex, UK). Breakfast, lunch, and dinner were served
with snacks when necessary. Dietary intakes were analyzed as
previously described for the 7-d weighed food intakes.

Analysis

Comparisons of EE and metabolic rate during sleep, waking,
and net exercise were made between groups.

Results for 24-h EE were broken down into the sleep and wak-
ing periods. Sleep times were noted from the activity diaries in
combination with the decline in EE values at night and the rise
of these values in the morning. Because there was a slight vari-
ation in the sleep and waking times between and within groups,
these times were used to calculate the sleeping and waking EE
values, in kJ/min. This calculation gave the sleeping metabolic
rate (SMR) and the waking metabolic rate (WMR) and enabled
a more accurate comparison of values between the experimental
groups. Results were expressed in absolute terms and per unit
body weight and per unit LBM.

To distinguish between EE as a result of exercise and RMR
and thermic effect of feeding on the exercise day, the net energy
cost of the exercise was calculated as follows. First, the gross
energy cost of the exercise was calculated, which included the
30-min exercise period plus the immediate 30-min postexercise
during which EE returned to the preexercise level. For each ex-
TABLE 1
Anthropometric indexes*  

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Weight (kg)</th>
<th>Height (m)</th>
<th>BMI†</th>
<th>Body fat (%)</th>
<th>Lean body mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>25 ± 0.9</td>
<td>71.6 ± 1.23</td>
<td>1.80 ± 0.02</td>
<td>22.2 ± 0.57</td>
<td>14.8 ± 1.30</td>
<td>61.0 ± 1.02</td>
</tr>
<tr>
<td>Moderately active</td>
<td>25 ± 1.2</td>
<td>72.1 ± 1.73</td>
<td>1.79 ± 0.01</td>
<td>22.5 ± 0.5</td>
<td>13.3 ± 1.03</td>
<td>62.6 ± 1.20</td>
</tr>
<tr>
<td>Highly active</td>
<td>25 ± 0.6</td>
<td>73.7 ± 1.30</td>
<td>1.78 ± 0.02</td>
<td>23.3 ± 0.51</td>
<td>10.6 ± 0.46†§</td>
<td>66.0 ± 1.38§</td>
</tr>
</tbody>
</table>

* ± SEM; n = 10 per group.
† In kg/m².
§ Significantly different from moderately active, P < 0.04.
§ Significantly different from sedentary, P < 0.01.

Exercise period, nonexercise metabolic rate was taken as the sum of EE during the 30-min preexercise and 30-min postrecovery (after values had returned to baseline). This value was subtracted from the gross energy cost to calculate the net energy cost of the activity.

Gross EE of exercise = EE during 30 min of exercise + EE 30 min immediately postexercise

Net EE of exercise = gross EE of exercise – (30 min preexercise EE + 30 min postexercise EE after metabolic rate had returned to baseline)

In the sedentary group one individual missed the afternoon session of exercise. The results for this individual were therefore excluded from the EE calculations for this day because he was unable to repeat the measurement.

To check whether any differences in EE were due to small differences in activity, other than the set exercise, the amount of time spent in various activities was calculated from the activity diaries.

Statistical analysis

One-way analysis of variance was used to test for significant differences between groups and days. Post hoc analysis was performed by using Fisher’s least-significant-difference (LSD) test. A two-sample t test was used to determine two-sample differences. Statistical analysis was performed by using the Number Cruncher Statistical System, version 5.03 (1990, Kaysville, Utah). A significant difference was established at P < 0.05.

TABLE 2
Total 24-h, sleep, and waking energy expenditure (EE)*  

<table>
<thead>
<tr>
<th>Group</th>
<th>24-h EE (kJ/d)</th>
<th>Sleep EE (kJ/d)</th>
<th>Waking EE (kJ/d)</th>
<th>24-h EE (kJ/d)</th>
<th>Sleep EE (kJ/d)</th>
<th>Waking EE (kJ/d)</th>
<th>Net exercise EE (kJ/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>8669 ± 227</td>
<td>2281 ± 88</td>
<td>6388 ± 235</td>
<td>11063 ± 370†</td>
<td>2470 ± 134</td>
<td>6745 ± 332</td>
<td>1844 ± 97</td>
</tr>
<tr>
<td>Moderately active</td>
<td>9328 ± 357</td>
<td>2327 ± 105</td>
<td>7001 ± 286</td>
<td>11609 ± 328†</td>
<td>2516 ± 92</td>
<td>7056 ± 193</td>
<td>2037 ± 122</td>
</tr>
<tr>
<td>Highly active</td>
<td>9908 ± 344‡</td>
<td>2621 ± 130</td>
<td>7287 ± 227§</td>
<td>11915 ± 395‡</td>
<td>2583 ± 122</td>
<td>7484 ± 277</td>
<td>1848 ± 84</td>
</tr>
</tbody>
</table>

* ± SEM; n = 10 per group except sedentary group, exercise day (n = 9).
† Significantly different from sedentary-day 24-h EE, P < 0.001.
‡§ Significantly different from sedentary: ‡P < 0.01, §P < 0.02.

Results

Anthropometric indexes for each group are shown in Table 1. Age, weight, height, and body mass index (BMI) were closely matched between groups. However, percentage body fat was significantly lower in the highly active group than in the sedentary and moderately active groups: 10.6% vs 14.8% (P < 0.01) and 13.3% (P < 0.04), respectively. Consequently, the LBM of the highly active group was greater than that of the sedentary (P < 0.01) and moderately active groups (NS).

Table 2 shows EE values for the total 24 h and sleep, waking, and exercise periods on the sedentary and exercise days. On both days the highly active group had the greatest total 24-h EE followed by the moderately active group and then the sedentary group, but these differences were significant only for the highly active group vs sedentary group on the sedentary day. Total sleep and waking EE followed the same pattern of differences between groups with only the waking EE being significantly greater in the highly active group than in the sedentary group on the sedentary day.

Table 3 shows the mean metabolic rate (kJ/min) for the total 24 h and sleep, waking, and, net exercise components of the 2 d. Expression of the results per metabolic rate allowed for a more accurate comparison of waking and sleeping metabolism because the duration of these components varied. Comparison of the WMR and SMR of the three groups showed once more that the highly active group had the greatest values, followed by the moderately active group and then the sedentary group; both the WMR and SMR on the sedentary day being significantly greater in the highly active group than in the sedentary group. Expression of
TABLE 3
Twenty-four-hour, sleep, and waking metabolic rate values per person, body weight, and lean body mass (LBM)*

<table>
<thead>
<tr>
<th></th>
<th>Sedentary day</th>
<th>Exercise day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 h</td>
<td>Sleep</td>
</tr>
<tr>
<td></td>
<td>kJ</td>
<td>kJ</td>
</tr>
<tr>
<td><strong>EE/min</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary</td>
<td>6.01 ± 0.17</td>
<td>4.41 ± 0.08</td>
</tr>
<tr>
<td>Moderately active</td>
<td>6.47 ± 0.25</td>
<td>4.70 ± 0.21</td>
</tr>
<tr>
<td>Highly active</td>
<td>6.89 ± 0.13</td>
<td>5.21 ± 0.29</td>
</tr>
<tr>
<td><strong>EE·body wt -1·h -1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary</td>
<td>5.04 ± 0.13</td>
<td>3.70 ± 0.08</td>
</tr>
<tr>
<td>Moderately active</td>
<td>5.42 ± 0.25</td>
<td>3.95 ± 0.21</td>
</tr>
<tr>
<td>Highly active</td>
<td>5.59 ± 0.17</td>
<td>4.24 ± 0.21</td>
</tr>
<tr>
<td><strong>EE·LBM -1·h -1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary</td>
<td>5.92 ± 0.17</td>
<td>4.37 ± 0.08</td>
</tr>
<tr>
<td>Moderately active</td>
<td>6.26 ± 0.29</td>
<td>4.54 ± 0.21</td>
</tr>
<tr>
<td>Highly active</td>
<td>6.26 ± 0.17</td>
<td>4.75 ± 0.25</td>
</tr>
</tbody>
</table>

* x ± SEM; n = 10 per group except sedentary group, exercise day (n = 9).
†§ Significantly different from sedentary: †P < 0.01, §P < 0.03.
| Significantly different from highly active, P < 0.05.

The metabolic rate per unit body weight and LBM (Table 3) reduced the previously observed intergroup differences, especially per kg LBM. Only a slightly greater 24-h metabolic rate and WMR were observed for the active groups compared with the sedentary group on the sedentary day, although the highly active group still showed a tendency toward a greater SMR compared with the sedentary group (+8.8%). On the exercise day, metabolic rate values per unit LBM were not different in the three experimental groups. By contrast, expression of the net energy cost of the exercise in terms of body weight or LBM resulted in significantly greater for the highly active group (+22, +57, and +10 min for the highly active, moderately active, and sedentary groups, respectively).

A summary of the time spent in various activities during each day’s EE measurement is shown in Table 4. All groups spent similar amounts of time sitting eating, lying resting, and sleeping. The total amount of time spent in the more active occupations of sitting quietly and lying sleeping in all groups. Also, there was a slight increase in the amount of time spent sitting actively (+22, +57, and +10 min for the highly active, moderately active, and sedentary groups, respectively).

The highly active group had a significantly greater habitual and therefore experimental daily EI compared with the sedentary group on the sedentary day, although the highly active group (+26%) and the moderately active group (+24%) compared with the highly active group (+20%). Metabolic rate during the daytime (nonexercising) and sleep period was nonsignificantly increased on the exercise day, again more so in the sedentary (+4.9% and +7.6%, respectively) and moderately active groups (+3.5% and +5.1%, respectively) than in the highly active group (+2.2% and -1.1%, respectively).

**TABLE 4**
Average minutes spent in various activities during 24-h energy-expenditure (EE) measurements*

<table>
<thead>
<tr>
<th></th>
<th>S4</th>
<th>S5</th>
<th>Sn</th>
<th>Ls</th>
<th>Lm</th>
<th>St</th>
<th>Pt</th>
<th>Ex</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sedentary day</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary group (n = 10)</td>
<td>574 ± 211</td>
<td>56 ± 12</td>
<td>79 ± 100</td>
<td>145 ± 160</td>
<td>514 ± 40</td>
<td>25 ± 33</td>
<td>47 ± 41</td>
<td>0 ± 0</td>
<td>1440 ± 0</td>
</tr>
<tr>
<td>Moderately active group (n = 10)</td>
<td>663 ± 182</td>
<td>52 ± 24</td>
<td>15 ± 30</td>
<td>144 ± 172</td>
<td>497 ± 35</td>
<td>28 ± 49</td>
<td>41 ± 39</td>
<td>0 ± 0</td>
<td>1440 ± 0</td>
</tr>
<tr>
<td>Highly active group (n = 10)</td>
<td>637 ± 183</td>
<td>49 ± 9</td>
<td>58 ± 149</td>
<td>154 ± 162</td>
<td>507 ± 28</td>
<td>6 ± 11</td>
<td>29 ± 18</td>
<td>0 ± 0</td>
<td>1440 ± 0</td>
</tr>
<tr>
<td><strong>Exercise day</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary group (n = 9)</td>
<td>504 ± 205</td>
<td>52 ± 7</td>
<td>101 ± 142</td>
<td>106 ± 130</td>
<td>520 ± 50</td>
<td>25 ± 36</td>
<td>42 ± 27</td>
<td>90 ± 0</td>
<td>1440 ± 0</td>
</tr>
<tr>
<td>Moderately active group (n = 10)</td>
<td>531 ± 227</td>
<td>50 ± 15</td>
<td>72 ± 162</td>
<td>110 ± 188</td>
<td>520 ± 39</td>
<td>24 ± 41</td>
<td>43 ± 34</td>
<td>90 ± 0</td>
<td>1440 ± 0</td>
</tr>
<tr>
<td>Highly active group (n = 10)</td>
<td>561 ± 212</td>
<td>52 ± 17</td>
<td>66 ± 128</td>
<td>122 ± 149</td>
<td>506 ± 40</td>
<td>15 ± 24</td>
<td>28 ± 19</td>
<td>90 ± 0</td>
<td>1440 ± 0</td>
</tr>
</tbody>
</table>

* x ± SD. S4, sitting quietly (reading, watching television, or listening to music); S5, sitting actively (writing); Sn, sitting eating; Ls, lying relaxing (resting, watching television, reading, or listening to music); Lm, lying sleeping; St, standing; Pt, pottering (a series of small undefined activities); Ex, designated exercise (stepping and cycling).
group and moderately active group (Table 5), whereas the contribution of macronutrients to the daily EI was similar (15–16% protein, 32–34% fat, and 49–53% carbohydrate for all groups and on each experimental day).

Energy expenditure and metabolic rate results for the five highly active subjects who completed measurements for the two sedentary days posttraining and post nontraining are shown in Table 6. The difference between the 24-h EE of the sedentary day, on which training had not occurred the day before (post nontraining), compared with the day when training had been performed before the 24-h EE measurement (posttraining) was −277 kJ (−2.7%, NS) whereas SMR fell by 4.0% (NS) and WMR by 2.1% (NS). LBM, EI, and activity were similar between the 2 sedentary days; therefore, expression of results per unit LBM did not affect the comparisons.

Discussion

Investigations into the effect of exercise on metabolic rate have either focused on the immediate postexercise elevation in metabolic rate or differences in RMR and the response to thermogenic stimuli between athletes and nonathletes. Our investigation used a room respirometer to investigate the effect of habitual, long-term exercise patterns on daily EE and metabolic rate during a sedentary day and an active day. Standardized exercise on the active day was designed to mimic nontraining activity outside the room respirometer. We aimed to determine whether or not regular exercise has any long-term stimulatory effect on metabolic rate well beyond the time of exercise itself.

Over 24 h subjects closely matched for height, weight, and age who participated in regular physical exercise generally had a nonsignificantly greater total 24-h EE during both sedentary and exercise protocols compared with their habitually sedentary counterparts. The only significant difference was found between the highly active group and the sedentary group on the sedentary day (P < 0.01). Between-group differences in 24-h EE were greater on the sedentary day (+1239 kJ, +580 kJ, and +659 kJ, for the highly active vs sedentary, highly active vs moderately active, and moderately active vs sedentary groups, respectively) than on the exercise day (+853 kJ, +307 kJ, and +546 kJ, respectively). A greater metabolic rate during both the sleeping and waking hours contributed to the increased 24-h EE of the highly active group compared with the sedentary group (P < 0.03 and P < 0.01, respectively). Other group differences in WMR and SMR were not significant. Differences in EE between groups could not be explained by the amount of time spent in various activities. Despite close matching of subjects for weight, height, and age, we found a significantly lower percent body fat in the highly active group than in the other two groups, leading to differences in LBM. We recognize that there are limitations to the accuracy of LBM values determined from skinfold thicknesses. However, the subjects were lean and measurements were made by the same individual, which minimizes errors. Relative differences between groups would be the same. Because LBM is highly correlated with metabolic rate and 24-h EE (22–24), we expressed results per unit LBM. With results expressed in this way, differences in 24-h EE and metabolic rate between the three groups were reduced. On the sedentary day, both the highly active and moderately active groups had almost identical 24-h EE and WMR·kg LBM·−1·h−1, with these values being only slightly greater than those of the sedentary group. However, the SMR of the highly active group was still 8.6% greater than that of the sedentary group although the difference was not statistically significant. On the exercise day, 24-h EE, WMR, and SMR/kg LBM were not different for all groups. Therefore, the differences in metabolic rate between the three groups were largely a result of the greater LBM of the highly active and moderately active groups compared with the sedentary group. We found no evidence of any significant long-term effect on metabolic rate per unit active tissue although there was a nonsignificant trend on the sedentary day for SMR (taken as proxy for BMR) to increase with increasing level of habitual exercise, even when expressed per unit LBM. Had the highly active subjects not trained the day before the daily EE measurements, a slight reduction in 24-h EE and SMR might have been observed because 24-h EE and SMR fell by 2.7% and 4%, respectively, in the subsample of highly active subjects who rested the day before a second sedentary 24-h EE measurement. The reduction in SMR was slightly less than the significant, 6% reduction in RMR reported by Tremblay et al (25) after a 3-d interruption of training in male athletes. To detect significant differences of the magnitude we observed in these 5 subjects, we would have required a sample size of >10 subjects.

The significantly greater EI of the highly active group during the measurement of EE may have contributed slightly to their greater 24-h EE. With a constant diet-induced thermogenesis of 10%, this contribution would have amounted to a difference of 126 and 357 kJ in daily EE for the moderately active and highly active groups, respectively, compared with the sedentary group. However, it has been reported that the thermic response to a meal is reduced in highly trained subjects compared with sedentary or moderately active subjects (7, 9). In view of this reduction, the effect of feeding diets with different EIs to subjects during their chamber stays would be minimal in terms of its effect on the overall results and conclusions.

Our results agree with those of Schulz et al (15), who also found no difference in daily EE and SMR between the trained and untrained males with results expressed per unit LBM. Athletes in the study by Schulz et al comprised runners, cyclists, and triathletes whereas in our investigation highly active subjects were mainly kayak paddlers. Our trained subjects combined kayak training with other training modes, including weight training, circuit training, cycling, and running. These differences in type of training between subjects in our study and that of Schulz et al did not appear to affect the final conclusion with respect to

<table>
<thead>
<tr>
<th>Group</th>
<th>Habitual</th>
<th>Sedentary day</th>
<th>Exercise day</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR</td>
<td>11453 ± 748</td>
<td>11273 ± 739</td>
<td>11264 ± 680</td>
</tr>
<tr>
<td>WMR</td>
<td>12692 ± 827</td>
<td>12306 ± 756</td>
<td>12356 ± 794</td>
</tr>
<tr>
<td>Highly active</td>
<td>15007 ± 853†</td>
<td>15754 ± 937†</td>
<td>15515 ± 1029†</td>
</tr>
</tbody>
</table>

* x ± SEM, n = 10 per group.
† Significantly different from moderately active, P < 0.02.
‡ Significantly different from sedentary, P < 0.001.
the effect of high levels of training on EE, i.e., high levels of physical activity do not increase daily EE independently of LBM.

On the exercise day, the specified activity increased 24-h EE significantly in all groups compared with the sedentary day (\(P < 0.001\)), the increase being greatest in the sedentary group (2394 kJ), followed by the moderately active group (2281 kJ), and then the highly active group (2008 kJ). The differences are slightly greater than the calculated net exercise values by 550, 244, and 160 kJ, respectively, indicating that the set exercise stimulated SMR and WMR more in the habitually sedentary subjects than in those who habitually exercise. These differences may have been due to the higher relative intensity of the exercise in the sedentary than in the active groups. We did not adjust the relative intensity of the exercise because normal daily activities would represent a different physical challenge to subjects and we wanted to reproduce a typical (nontraining) day in the room respirometer. The slightly elevated SMR and WMR on the exercise day were not significantly greater compared with those on the sedentary day. This result confirms the findings of others who measured daily EE with and without moderate exercise protocols (26-28).

In summary, the results from this study showed that on a sedentary day the EE and metabolic rate of highly active and moderately active individuals was increased compared with their sedentary counterparts, significantly so for highly active subjects when expressed per person but not per unit body weight or LBM. With the inclusion of a set amount of activity, similar to a typical nontraining day outside the room, EE and metabolic rate were not significantly different between the groups. We found no significant long-term stimulatory effect of regular, moderate, or intense training on the energy metabolism of body tissue independently of LBM. However, the increased LBM resulted in the habitually highly active and moderately active subjects having a daily EE 14% and 8% higher, respectively, than the habitually sedentary subjects even on a completely sedentary day. This is equal to a difference of \(\approx 1200\) and 600 kJ/d, respectively.

We thank all those who gave their time to take part in the study. Without their generous cooperation we would not have been able to complete this research.

References


TABLE 6
Twenty-four–hour energy expenditure (EE) and metabolic rate on posttraining and post nontraining sedentary days in highly active subjects*


