A decrease in physical activity affects appetite, energy, and nutrient balance in lean men feeding ad libitum

R James Stubbs, Darren A Hughes, Alexandra M Johnstone, Graham W Horgan, Neil King, and John E Blundell

ABSTRACT

Background: It is not clear how decreased activity quantitatively affects energy balance (EB) in subjects feeding ad libitum. Objective: We assessed the effect of an imposed sedentary routine on appetite, energy intake (EI), EB, and nutrient balance in lean men for 7 d. Design: Six men with a mean (±SD) age of 23.0 ± 2.3 y, weight of 69.2 ± 11.4 kg, and height of 1.76 ± 0.07 m were each studied twice during a sedentary [1.4 × resting metabolic rate (RMR)] and a moderately active (1.8 × RMR) regimen. During each treatment, they resided in the whole-body indirect calorimeter for the 7 d and had ad libitum access to a medium-fat diet of constant, measurable composition. Meal size, frequency, and composition were continually monitored. Motivation to eat was recorded during waking hours. Subjects were weighed in light clothing each morning, and their weight was corrected to nude. Results: Energy expenditure was 9.7 and 12.8 MJ/d [P < 0.01; SE of the difference between means (SED) = 0.41] during the sedentary and active regimens, respectively. EI was 13.5 and 14.4 MJ/d (P = 0.463, SED = 1.06), respectively. There was no regimen effect on hunger, appetite, or body weight. By day 7, cumulative EB was 26.3 and 11.1 MJ, respectively. Conclusions: Reducing a level of physical activity from 1.8 to 1.4 × RMR can markedly affect EB. A sedentary routine does not induce a compensatory reduction of EI and leads to a significantly positive EB, most of which is stored as fat. Am J Clin Nutr 2004;79:62–9.

KEY WORDS Exercise, sedentariness, calorimetry, humans, energy balance, appetite

INTRODUCTION

Two factors associated with modern lifestyles—the diet we eat and the sedentary nature of our daily routines—are considered particularly conducive to weight gain. The Western diet has increased in energy density, fat, and readily assimilated starches and decreased in fiber, micronutrient density, and, often, moisture in comparison with previous periods of human existence (1). These changes are partly responsible for elevating energy intake (EI) and body weight (1, 2). It has been noticed by some that reported amounts of EI appear to be dropping in parallel with a decrease in energy requirements (3). The extent to which this phenomenon is real or is due to an increase in the prevalence of misreporting of dietary intakes is currently unclear (4).

Average daily energy expenditure (EE) appears to be less than was typical of the population several decades ago (5). Objective measures of free-living EE, obtained with the use of tracers, are a relatively recent phenomenon (6). Nonetheless, it is generally accepted that Western populations are more sedentary than they used to be (5, 7, 8). Black et al (9) used tracer studies to estimate that the established limits of daily total EE (TEE) ranged from 1.2 to 4.5 × basal or resting metabolic rate (RMR) over periods of 2 wk or more. Intense, sustained activity in most people tends to be a little lower: ≈2.3–2.9 × RMR (10). The general population appears less variable, having overall activity in the range of 1.4–1.8 × RMR (9). Given that modern lifestyles are apparently so sedentary, then, the question arises of whether there is much possibility of significantly affecting EB by further reducing physical activity within the normal range.

Despite the general view that modern lifestyles are more sedentary than previous lifestyles, there is very little evidence to directly link this change to the development of a positive EB. Instead, a number of intuitively obvious arguments and proxy indicators of physical activity have been used in (largely) cross-sectional comparisons to suggest that the number of hours spent watching television, car ownership, and the use of mobile phones are all factors lowering average physical activity in the population and further predisposing people to weight gain (3, 7, 11). Despite the attractiveness of these arguments, few studies have actually attempted to assess the effect on EB of imposing sedentary routines, within the normal range of activity, on healthy humans who were feeding ad libitum. The effects of inactivity on appetite, EI, or both were assessed in persons with disease (10), in persons on bed rest at a 6° head-down tilt (as a model of zero gravity; 12), and in persons (ie, astronauts) who have spent time in space (13). In addition,
the effect of imposing a sedentary routine on healthy subjects was examined in the short term (14, 15). However, King et al (16) noted that studies of this duration and involving a variety of conditions generally produced no change in feeding behavior. To the best of our knowledge, no one has examined in detail the effects on EB and nutrient balance of varying the level of physical activity within the normal range for Western adults over a period of >2 d. The purpose of this study was to clamp daily TEE at ≈1.4 and 1.8 × RMR and to examine the effect on the motivation to eat and on EI for 7 consecutive days in 6 men who were continually resident in a whole-body indirect calorimeter.

SUBJECTS AND METHODS

Subject recruitment

Six healthy male volunteers [mean ± SD: age, 23.0 ± 2.3 y; weight, 69.2 ± 11.4 kg; height, 1.76 ± 0.07 m; body mass index (BMI; in kg/m²), 22.2 ± 2.4] were recruited by advertisement. They were normal-weight, nondepressed healthy men who were not taking any medication and were not engaged in any exercise training. They were given a medical examination before beginning the study. The men were not informed of the true purpose of the study but were told that the study objective was to examine the repeatability of substrate oxidation and storage measurements in subjects feeding ad libitum on identical diets, but at different levels of activity.

Height was measured to the nearest 0.5 cm by using a stadiometer (Holtain Ltd, Crymych, United Kingdom). Subjects were weighed in light clothing (and their weight was corrected to nude) each morning of the study, after voiding and before eating, to the nearest 50 g on a digital scale (DIGI DS-410; CMS Weighing Equipment Ltd, London). Subjects were unable to monitor their weight during their stay in the calorimeter because the digital display for the scales was outside the calorimeter. Before the start of the study, RMR was measured with the use of a ventilated hood system (Deltatrac II, MBM-200; Datex Instrumentarium Corporation, Helsinki) in subjects who had fasted overnight. RMR was calculated by using the equations of Elia and Livesey (17). All subjects were interviewed and informed of the procedures involved in the study before they signed a consent form. The Joint Ethical Committee of Grampian Health Board and the University of Aberdeen approved the study.

Experimental design

Each subject was studied twice in 9-d protocols that involved 170 h (7 d) of continuous whole-body indirect calorimetry. The 2 treatments corresponded to sedentary and active regimens. Residing in the calorimeter for 7 d naturally imposes on the subject a sedentary regimen of ≈1.3 × RMR. Exercising for a specific duration and at a specific intensity can further elevate EE. For both treatments, subjects adhered to a prescribed intensity and duration of exercise by using a bicycle ergometer (Monark, Stockholm). During the sedentary regimen, subjects completed two 40-min exercise sessions/d (at 1100 and 2000) at 60 rpm and 1.0 kp (≈60 W) to increase EE to ≈1.4 × RMR. During the active regimen, subjects completed three 40-min exercise sessions/d (at 1100, 1400, and 2000) at 60 rpm and 1.5 kp (≈90 W) to increase EE to ≈1.8 × RMR. The order of the 2 treatments was randomized across subjects, and each study period was separated by ≈1 wk.

On days –2 and –1 (the equilibration period), subjects were fed a diet designed to match maintenance energy requirements, which were estimated at 1.6 × RMR. This may have led to a slight underestimation of requirements in this group, because all were moderately active men whose likely free-living EE would be closer to 1.7–1.8 × RMR (9). The dietary protocol was standardized for all subjects. The diet used in the equilibration period comprised 47% of energy as carbohydrate, 40% as fat, and 13% as protein. This diet was served in 3 isoenergetic meals. This composition was identical to the ad libitum diet of this experiment. At 0800 on day 1, each subject entered the whole-body indirect calorimeter, having previously emptied his bladder. Subjects remained continually resident in the calorimeter for the next 7 d, on either the sedentary or the active regimen. During these 7 d (days 1–7), they had access to a medium-fat diet of constant measurable composition (see below). Thus, EI, nutrient intake, EE (oxidation), and EB could be measured throughout this period. On the morning of day 8, subjects left the calorimeter. The macronutrient composition of each item of the diet, the actual recipes used, and the details of the 3-d rotating menu can be obtained by contacting the corresponding author.

The daily routine followed by the subjects was as follows. Subjects rose at 0800 and had 30 min to prepare for the day (wash, shave, dress, etc). Lights out was at 2300, with 30 min beforehand to prepare for bed. They cycled at the intensity prescribed for the treatment they were engaged in. Urine samples were collected every 4 h and overnight (8 h) for nitrogen analysis. Nitrogen content was analyzed by using the Foss Heralus Nitrogen Analyser (Macro N; Foss Electric UK Ltd, Wheldrake, United Kingdom).

Formulation and preparation of the diets

The composition of each diet’s dishes in terms of energy, fat, carbohydrate, protein, and nonstarch polysaccharide was calculated from McCance and Widdowson’s The Composition of Foods, 5th edition, and supplements (18). The diets for maintenance days –2 and –1 were formulated to be of a very similar energy content and density so that differences in amount of food ingested did not influence ad libitum food intake on the subsequent days. The ad libitum diet for days 1–7 was formulated so that each item on the 3-d rotating menu comprised 47% of energy as fat, 40% as carbohydrate, and 13% as protein and contained 550 kJ/100 g wet weight of food. Thus, the food intake directly paralleled EI. The food was prepared by the dietetic research assistant in the metabolic kitchen. Thus, the ad libitum diets were formulated to be composed, as far as possible, of normal, everyday ingredients and to contain recognizable food that varied little in composition (eg, prepared foods were not used). The diets had to be palatable and appealing to the volunteers. Foods were pilot-tested and altered, if necessary, to resemble familiar food items, but also to have the appropriate compositions. These procedures were very similar to those described previously, and the diets were used elsewhere (19).
Presentation of the diets and measurement of food intake

Subjects were resident in the Human Nutrition Unit for the duration of the study. On days −2 and −1, meals were placed in a labeled refrigerator for subjects to consume in the volunteer dining room. While they were resident in the calorimeter, subjects requested food and drink from the given menu by telephone. Within the framework of the 3-d rotating menu, subjects determined their own meal times. Subjects could forego or request repeats of meals and could eat as much or as little of each item on the diet as they wished. Food was presented to the subjects (through an airtight hatch in the chamber door) in the following amounts: breakfast, 600 g; main courses, 400 g; sweets, 150 g; milkshakes, 300 g; and hot drinks, 350 g. Extra portions were readily available on request. All food items were homogeneous and of a known composition, which was calculated from food tables (18), and each item was presented in a separate container. This allowed each item to be weighed before and after the meal to the nearest gram. The energy content of each item of the diets was checked by bomb calorimetry (autobomb CBA-301 Series; Gallenkamp, London), which, on average, agreed with the food tables to within 2–3%. The subjects entirely determined the time, frequency, and quantity (but not composition) of all meals and snacks, by ordering food from the menu by telephone.

Tracking motivation to eat

Visual analogue scales were completed for every waking hour, on paper questionnaires, throughout each study day to assess changes in subjective motivation to eat. The specific questions and the range of answers were “How hungry do you feel?” (not at all hungry—as hungry as I have ever felt), “How full do you feel?” (not at all full—as full as I have ever felt), “How strong is your desire to eat?” (very weak—very strong), “How much do you think you could eat now?” (nothing at all—a large amount), “Preoccupation with thoughts of food” (no thoughts of food—very preoccupied, difficult to concentrate on other things), and “Urge to eat” (no thoughts of food—very preoccupied—difficult to concentrate on other things). Subjects also completed pleasantness and satisfaction ratings 15 min after each meal as described previously (20).

Whole-body indirect calorimetry

The study was conducted in the 2 whole-body indirect calorimeters at the Rowett Research Institute, which are identical in design and layout. A previous report (20) described the chambers, their initial calibration, and ongoing system checks. The gas analyzers were calibrated before every run with the use of alpha standard gases, corrected to standard temperature and pressure (British Oxygen Company, Guilford, United Kingdom). During the run, the analyzers were corrected for drift every 3 h with the use of atmosphere as a reference.

Precision estimates for the chambers suggest that the SDs in the estimates of fat and carbohydrate oxidation are 21.7 and 18.9 kJ/h, respectively, which gives a CV for the calculated hourly substrate oxidation of 10.5% and 8.9%, respectively. Over the 24-h period, these values would be expected to decrease. This calculation excludes all other possible instrumental errors and all errors relating to coefficients and constants used in the calculation of substrate oxidation.

The major sources of calorimetric errors are the calibration of the ventilation rate, the linearity of the carbon dioxide analyzers, and the composition of the carbon dioxide span gas. These remained unchanged throughout the course of the study, and the same calorimeter was used for both runs for each subject. Thus, whereas errors in the calculation of substrate oxidation may not have been insignificant, they would have been primarily systematic and relatively constant over the course of the study and would have had little effect on the relative comparison across treatments.

As previously described (21), oxygen consumption and carbon dioxide production were estimated by using the rapid-response calculations of Brown et al (22). EE and substrate oxidation rates were calculated from oxygen and carbon dioxide exchanges and urinary nitrogen excretion by using the values of Livesey and Elia (23) for volumes of oxygen consumed per oxidized gram of protein, fat, and carbohydrate and the associated respiratory quotients.

Statistical analysis

Twenty-four-hour EI and nutrient intake, oxidation, and EB were analyzed by analysis of variance (ANOVA) with exercise regimen as a treatment factor and subject and order of treatments as blocking factors. In addition, cumulative EB and nutrient balance (calorimetry) were summarized by ANOVA.

The visual analogue ratings were analyzed with the use of ANOVA by calculating a mean rating for each 24-h period with exercise regimen as a treatment factor and subject as a blocking factor. To ensure a normal distribution, a square-root transformation was applied to postmeal ratings of pleasantness and satisfaction.

Changes in body weight from day 1 to day 7 were analyzed by ANOVA to test for treatment effects. For each treatment, t tests were used to test for significant changes in weight over the period. All analyses were performed with the use of the GENSTAT 5 statistical program (version 5.0; Rothampstead Experimental Station, Harpenden, United Kingdom).

RESULTS

Energy expenditure

The average daily EE and net macronutrient oxidation profiles for the 6 men on each regimen are summarized in Table 1. EE was significantly influenced by the intervention. Throughout the 7-d treatment period, average daily EE on the sedentary and active regimens, respectively, was 9.75 and 12.77 MJ/d (SED = 0.09, P = 0 < 0.001). Subjects expended on average 1.4 ± 0.09 × RMR and 1.8 ± 0.20 × RMR, respectively. There were no time (day) effects for TEE, which indicated that daily EE did not increase or decrease as the study progressed. By the end of 7 d, the difference in cumulative EE between treatments amounted to 21.06 MJ.

Energy and macronutrient intakes

The mean daily food, energy, and macronutrient intakes for the 6 men on each regimen are summarized in Table 2. On average, subjects consumed more food and drink on the active regimen than they did on the sedentary regimen (P = 0.011, SED = 0.156) with mean intakes of 4.11 and 3.49 kg/d,
respectively. There were no significant differences between treatments in the amount of food (excluding acaloric drinks) consumed across days 1–7. Subjects consumed an average of 2.73 and 2.57 kg food/d (P = 0.486, SED = 0.206) on the active and sedentary regimens, respectively. On average subjects consumed 1.37 and 0.91 kg fluid/d (P = 0.105, SED = 0.235) as drinks (a citrus-based soft drink, water, milk allowance) on the active and sedentary regimens, respectively. These fluids contributed only a small fraction of daily EI at 0.08 and 0.07 (P = 0.687, SED = 0.004) MJ/d, respectively.

Energy intakes did not differ significantly between treatments, giving mean values of 14.35 and 13.50 MJ/d (P = 0.463, SED = 0.004) MJ/d, respectively. Subjects consumed 2.09 ± 0.47 and 1.95 ± 0.14 × RMR on the active and sedentary treatments, respectively.

Energy and nutrient balance

There was no significant difference in EI and nutrient intakes, but EE varied systematically across treatments, which affected EB and nutrient balances. EB, measured as EI minus EE, became more positive ongoing from day 1 to day 7 on both treatments, as shown in Figure 1. Treatment effects on average daily EB did not differ significantly from each other (P = 0.102, SED = 1.08). Mean daily values were 1.59 and 3.75 MJ/d on the active and sedentary regimens, respectively. Cumulative EB amounted to 11.1 and 26.3 MJ by the end of day 7 on active and sedentary regimens, respectively. This was significantly different from zero on the sedentary treatment only (P < 0.001).

The cumulative protein balance values of 3.7 and 3.9 MJ on the active and sedentary regimens, respectively, do not take account of extraneous losses from sweat, feces, and other bodily fluids (24). A correction of 0.5 g N/d (equivalent to 0.053 MJ/d or 0.372 MJ/wk) can be applied, which calculates cumulative protein balance to be 3.3 and 3.5 MJ on the active and sedentary regimens, respectively. The cumulative change in protein balance (with the correction applied for extraneous nitrogen loss) is shown in Figure 2. Whereas carbohydrate balance was virtually identical by the end of day 7 of both treatments (Figures 3 and 4), the marked difference in EB between treatments was largely reflected in differences in fat balance.

EB, measured by change in body weight, did not differ significantly between treatments. On average, subjects gained

### TABLE 1
Average 24-h energy expenditure and macronutrient oxidation for the 6 subjects on days 1–7 of the sedentary and active regimens

<table>
<thead>
<tr>
<th>Day</th>
<th>Sedentary</th>
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<th>Active</th>
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<td>Energy Fat</td>
<td>Carbohydrate</td>
<td>Protein</td>
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<td>Energy Fat</td>
<td>Carbohydrate</td>
<td>Protein</td>
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<tr>
<td></td>
<td>MJ/d</td>
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<td></td>
<td>MJ/d</td>
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<tr>
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<td>1.18</td>
<td></td>
<td>12.49 4.98</td>
<td>6.26</td>
<td>1.25</td>
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<td>2</td>
<td>9.52 2.87</td>
<td>5.54</td>
<td>1.11</td>
<td></td>
<td>12.65 5.17</td>
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<td>1.24</td>
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<tr>
<td>3</td>
<td>9.50 2.97</td>
<td>5.42</td>
<td>1.11</td>
<td></td>
<td>12.82 4.90</td>
<td>6.68</td>
<td>1.24</td>
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<tr>
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<td>1.02</td>
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<td>6</td>
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<td>12.94 4.99</td>
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<td>7</td>
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<td>6.61</td>
<td>1.13</td>
<td></td>
<td>12.96 6.05</td>
<td>5.65</td>
<td>1.26</td>
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<td><em>x</em></td>
<td>9.75 2.69</td>
<td>5.90</td>
<td>1.16</td>
<td></td>
<td>12.77 5.11</td>
<td>6.37</td>
<td>1.29</td>
<td></td>
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<tr>
<td>Total</td>
<td>68.29 18.82</td>
<td>41.31</td>
<td>8.15</td>
<td></td>
<td>89.35 35.76</td>
<td>44.56</td>
<td>9.03</td>
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The SEs of the difference between means were as follows for daily measures (MJ/d): energy, 0.474; fat, 1.063; carbohydrate, 0.838; and protein, 0.183. The corresponding values were as follows for the means (MJ/d): energy, 0.180; fat, 0.307; carbohydrate, 0.321; and protein, 0.118.

### TABLE 2
Average 24-h intakes of energy and macronutrients for the 6 subjects on days 1–7 of the sedentary and active regimens

<table>
<thead>
<tr>
<th>Day</th>
<th>Sedentary</th>
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<th>Active</th>
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<td>Carbohydrate</td>
<td>Protein</td>
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<td>Carbohydrate</td>
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<td></td>
<td>MJ/d</td>
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<td>MJ/d</td>
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<tr>
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<td>15.1 6.0</td>
<td>7.1</td>
<td>1.9</td>
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<td>13.9 5.5</td>
<td>6.6</td>
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<td>14.1 5.8</td>
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<tr>
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<td>14.5 6.0</td>
<td>6.8</td>
<td>1.8</td>
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<td>14.2 5.8</td>
<td>6.6</td>
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<tr>
<td>6</td>
<td>12.4 5.0</td>
<td>5.9</td>
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<td>6.4</td>
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<td>7</td>
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<td>6.4</td>
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<td>14.2 5.6</td>
<td>6.7</td>
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<td>x_</td>
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<td>1.7</td>
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<td>14.4 5.8</td>
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<tr>
<td>Total</td>
<td>94.5 37.8</td>
<td>44.5</td>
<td>11.9</td>
<td></td>
<td>100.2 40.6</td>
<td>46.9</td>
<td>12.7</td>
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The SEs of the difference between means were as follows for daily measures (MJ/d): energy, 1.372; fat, 0.598; carbohydrate, 0.684; and protein, 0.183. The corresponding values were as follows for the means (MJ/d): energy, 0.814; fat, 0.376; carbohydrate, 0.402; and protein, 0.110.

The total, cumulative total over the 7 d.

2 Total, cumulative total over the 7 d.
0.66 and 0.90 kg in total on the active and sedentary treatments, respectively, between day 1 and day 7 ($P = 0.793$, SED = 0.846). Change in body weight differed significantly from zero on the sedentary regimen only ($P = 0.001$). Mean daily values for EB (assessed as EI – EE) were 1.59 and 3.75 (SED 1.08) MJ/d on the active and sedentary regimens, respectively. It can be assumed that the energy cost of weight gain in a group of lean men would approximate 31 MJ/kg (25). Average cumulative energy imbalance amounted to 11.1 and 26.3 MJ over 7 d on the active and sedentary regimens, respectively. This gives an estimated change in body weight of $\approx 0.4$ and $\approx 1.0$ kg, respectively, which is very similar to the actual weight changes observed. These estimates are within $\pm 0.5$ MJ/d of the estimates of EB from the data for EE – EI.

Subjectively rated hunger and fullness

The average values for the subjective sensations of hunger, fullness, desire to eat, prospective consumption, preoccupation with thoughts of food, and urge to eat, together with the $F$ ratios and probability values for the main effects, are shown in Table 3. There were no significant treatment effects for any of the subjective sensations measured. Unfortunately, thirst was not measured in this study.

Subjects rated the diets as similarly pleasant on both regimens, with mean scores of $87 \pm 3.6$ and $82 \pm 4.2$ on the sedentary and active regimens, respectively, during ad libitum feeding ($P = 0.886$, SED = 0.7). There was a significant independent effect of meal, with breakfast rated as less pleasant than lunch or dinner: the average ratings were $82 \pm 4.2$, $85 \pm 3.9$, and $87 \pm 3.6$, respectively. Ratings of satisfaction were also similar between both treatments during the ad libitum feeding phase ($P = 0.711$, SED = 0.9), with mean scores of $87 \pm 3.6$ and $86 \pm 3.7$ for the sedentary and active regimens, respectively.

DISCUSSION

Effects of the intervention on daily TEE expenditure

The present study aimed to vary daily TEE at the extreme ends of the sedentary range of physical activity exhibited by most Western adults. In affluent societies, the limit of human daily EE appears to be 1.2–4.5 $RMR$ (9, 10, 26). Except in the extremely sedentary (eg, the bed-bound or elderly residential, largely nonambulatory patients), it is difficult for daily EE to fall much below 1.3 $RMR$ (26). In affluent societies, a total daily EE of $\approx 2.5 \times RMR$ represents a very active lifestyle. For relatively sedentary adults aged 18–64 y, EE averages 1.55–1.66 (9, 27–29). It therefore seems reasonable to consider $\approx 1.4 \times RMR$ as the low end and $1.8 \times RMR$ as the high end of the “sedentary” range of activity for healthy free-living adults. The environment of the calorimeter was ideal for the purposes of “clamping” daily EE. Subjects could be given set routines that would produce a daily EE of 1.4 and 1.8 $RMR$ for the sedentary and active regimens, respectively. The levels of exercise set were not unduly arduous. These data clearly show that varying physical activity in the range of 1.4–1.8 $RMR$ can have a marked effect on EE, which, if not
compensated for by changes in intake, could then markedly affect EB. A change in activity of one-half of this magnitude would change daily EE by 1.5 MJ/d, which represents the amount of exercise often prescribed in exercise interventions (29, 30). Clearly, then, there is scope within the sedentary routine, which suggests that the accumulation of a sedentary habit, the energy imbalance induced by a drop in daily TEE (41) or even sensory attributes – of a controlled diet (19) can affect EI and EB to a similar extent. There are several major determinants of EB in humans (1, 2). Increased sedentariness is likely to be important, but it is by far not the only factor predisposing Western adults to weight gain.

**Energy and nutrient balance regulation**

The present study suggests that, in subjects feeding ad libitum, the energy imbalance induced by a drop in daily TEE from 1.8 to 1.4 × RMR (∼15.2 MJ) was comparable with the difference in EB between subjects fed a 20% fat ad libitum diet and those fed a 60% fat ad libitum diet (∼20 MJ). This degree of energy imbalance may not continue to accrue monotonically. At an energy imbalance rate of 15.2 MJ/wk, subjects would attain an EB of 788 MJ over a year, for a weight gain of 25 kg/y (assuming 31 MJ/kg for the energy cost of weight gain). In an analysis of data from the National Health and Nutrition Examination Survey, the 30% of the population who gained weight most rapidly tended to do so at a rate of 1–2 kg/y (42).

Of their energy, fat, and carbohydrate intakes during the active and sedentary regimens, subjects retained 11% and 28%, 12% and 50%, and 7% and 5%, respectively. They did not oxidize 29% and 33%, respectively, of their protein intake. These values do not take account of extraneous nitrogen loss, which we have assumed to be 0.5 g/d (24). Retention values were 26% and 30% of the protein ingested on the active and sedentary regimens, respectively, when nonfecal, obligatory nitrogen loss was assumed to be 0.5 g/d. Fecal nitrogen losses are assumed with the use of 17 kJ/g as the metabolizable energy value (18) and of 19.68 kJ/g as the value for the enthalpy of combustion of mixed dietary protein (22).

Of the 11.1 MJ energy retained over the 7 d on the active regimen, 30% was protein, 21% was carbohydrate, and 43% was fat. After 7 d on the sedentary regimen, 13.5% was retained as protein, 12% as carbohydrate, and 72% as fat. Ostensibly, these data suggest that the sedentary regimen favored far more storage of fat as a proportion of the excess energy retained than did the active regimen. Indeed, these values suggest that the ratio of protein to energy (P ratio) deposited was twice as great on the active regimen as on the sedentary regimen. This can, however, be misleading. First, there is likely to have been a greater nonfecal loss of nitrogen on the active regimen, because of a higher sweat output. The above estimates assume nonfecal obligatory nitrogen loss of 0.5 g/d. Subjects exercised at a moderate intensity while the chamber temperature was ∼22°C. This consideration is unlikely to have exceeded a further 0.5 g/d or 0.37 MJ over the 7 d. Second, errors in the estimate of the percentage of energy retained as each macronutrient would be greater on the active regimen simply because the absolute amount of energy retained was only 42% of the energy retained on the sedentary regimen. Third, there may well have been slightly greater nitrogen retention on the active regimen. When subjects are in a negative EB, they lose lean tissue as well as fat tissue. Sustained moderate exercise results in the loss of nitrogen only half of that seen with a negative EB induced by diet alone (43). It is likely that this effect occurs in a state of positive EB. We are unaware of any overfeeding studies with and without exercise that assess protein-energy relations. There appears to be a difference in the protein:energy of the total energy retained; for the reasons given above, we feel that the estimates may slightly exaggerate this difference between treatments.

Bearing in mind that nitrogen is deposited along with energy, it is clear that the control of nutrient balance was largely hierarchical. Of the protein ingested, ∼70% was oxidized, and the remainder was disposed of largely by the positive nitrogen balance that accompanies energy storage (44, 45). Of the carbohydrate ingested, ∼95% was oxidized. Fat oxidation appears to have been secondary to the oxidative disposal of excess protein and carbohydrate (23, 46), because the balance of energy retained was in the form of fat. These findings are in accord with what is known of the physiologic regulation of nutrient balance (23, 46), taking into account protein-energy relations in a state of positive EB (44, 45). The active regimen may have promoted slightly greater nitrogen retention, as a
proportion of energy retained, but not as an absolute balance or as a proportion of protein ingested. Absolute nitrogen balance was similar on both regimens (see above).

Limitations of the present study

The work was conducted on a small number of nonrandomly selected, sedentary, lean, relatively young men who were able to tolerate the environment of the calorimeter for 7 d at a time. Not all people can do this. The results of this study may not be applicable to other population groups, such as children, the elderly, women, and the obese. Whereas the environment of the calorimeter is ideal for devising routines that effectively clamp daily TEE, the artificiality of this environment should always be borne in mind. The diets used in the present study were of a constant measurable composition. These diets allow subjects to alter the amount but not the composition of foods eaten. If given the choice, subjects might have selected a diet of a different composition in relation to different activity levels. The temperature of the calorimeter chamber was constant at $\pm 22 ^\circ C$, which is not dissimilar to the temperature of a centrally heated house. However, subjects were not able to lower the ambient temperature.

Conclusions

In the present study, varying the level of activity-induced daily EE within the sedentary range from 1.8 to $1.4 \times RMR$ markedly affected EE. Subjects increased their fluid intake in response to the increased water turnover associated with moderately intense bouts of activity. There was no significant change in EI across regimens and no tendency for EI to drop as the sedentary regimen progressed. This led to a marked difference in EB of 15.2 MJ over the 7 d. We conclude that an increase in sedentariness leads to no compensatory reduction in intake in response to the increased water turnover associated with moderate activity levels.

EI and to a markedly positive EB. It is possible to greatly increase in sedentariness leads to no compensatory reduction in intake in response to the increased water turnover associated with moderate activity levels.

REFERENCES