Eating, Drinking, and Cycling. A Controlled Tour de France Simulation Study, Part I


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Abstract


Sustained exhausting exercise is thought to depress appetite and food intake. The aim of the present investigation was to study the effect of intensive cycling exercise, with an energy expenditure comparable to values derived from the Tour de France, on food and fluid intake, energy balance, nitrogen balance, and nutrient oxidation. Thirteen highly trained cyclists consuming a normal carbohydrate (CHO)-rich diet (60 En%) were studied during a 7-day stay in a respiration chamber. Two preparation days were followed by a standardized resting day (3), after which the subjects completed two exhausting exercise days (4–5). On day 6 the standardized resting day was repeated. Food and fluid intake were measured by weighed procedures. Energy expenditure was calculated from continuous gas analysis. Energy and nitrogen losses were calculated from all measured excretes. The results showed that energy balance (EB) and nitrogen balance (NB) were positive on the first resting day and became negative on the exercise days. EB was positive again on the recovery day whereas NB remained negative. Nitrogen losses almost balanced N intakes (1.7 g·kg⁻¹) indicating an increased protein requirement. CHO oxidation exceeded CHO intake indicating endogenous CHO depletion. Contribution of CHO to energy exchange decreased from 51.4% ± 3.1% on day 4 to 40.6% ± 3.4% on day 5; this decrease was compensated by an increased fat oxidation. The food consumption pattern during days 4 and 5 was not different from days 2 and 6. Intake of meal consumption accounted for 30.5%–34.3% of total energy intake. Fluid consumption was adequate to compensate for the losses. These findings suggest an increased protein and carbohydrate requirement during days of prolonged intense exercise and an upper limit of energy intake (20 MJ) when consuming a normal CHO-rich diet.

Key words

food intake, fluid intake, energy balance, nitrogen balance, nutrient oxidation, cycling

Introduction

Consensus exists among most nutritionists that a normal, quantitatively and qualitatively well-balanced diet will be sufficient for any sportsman or -woman in any situation. However, it has recently been described that athletes performing intensive long-lasting exercise on a day-to-day basis are faced with the problem that consuming a normal well-balanced diet may become quite impossible (3). The reasons for this are the following: (1) The adverse effect between physical and mental stress and appetite; (2) intolerance for a large ingesta volume in the exercising athlete; (3) the reduced number of "resting" hours available for consumption and digestion.

It has been suggested that an inverse relationship exists between food intake and energy expenditure (15) so that it may be impossible to maintain regular meal schedules and sufficient energy intake on days that energy expenditure is very high. To compensate, athletes may fall into a nibbling eating pattern, more or less eating continuously throughout the day (16, 26), thus avoiding a large bulk of food in the stomach, which may induce abdominal distress. These nutritional problems in endurance athletes are well known in practice. However, no controlled studies have been performed. Another widespread belief is that the ingestion of water will always be better for reasons of rehydration and that there is no reason to combine the fluid with nutrients. This is in contrast to studies that show that glucose- and electrolyte-containing beverages restore plasma volume better than water alone (2, 8, 10), that ingestion of plain water may lead to abnormally low levels of plasma electrolytes, whenever the volumes of fluid replaced are substantial (13, 25, 35), and that the ingestion of carbohydrate-containing beverages improves performance compared with water ingestion (12). From observations of professional cyclists during the Tour de France (38) it is known that it is possible to maintain adequate energy and fluid intakes over a prolonged period of competition, even when energy expenditure exceeds 24 MJ/day and fluid intakes (to compensate losses) reach a level of more than 10 l/day. However, these cyclists were only able to do so during competition – which may last up to 8 h/day – by ingestion of energy-rich foods, to a large extent as CHO- and electrolyte-containing liquids. Those subjects who were not able to maintain energy and fluid balance frequently experienced malperformance and sometimes were forced to quit prematurely. This imbalance was commonly a result of poor food intake and/or gastrointestinal distur-

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balances such as diarrhea causing malabsorption and excessive fluid loss.

In professional cyclists CHO intake is closely related to energy intake since the major portion of energy in the selected diet (more than 60%) comes from CHO (38). Because CHO is a performance-limiting substrate in endurance exercise whenever exercise intensity exceeds 50%–60% of maximal oxygen uptake, it may be assumed that a negative energy balance, also leading to a negative CHO balance, may impair performance progressively.

This may happen as a result of insufficient glycogen repletion on a day-to-day basis. For this reason it was decided to study the effect of repeated exhaustive endurance exercise on nutritional indices in which the data obtained in cyclists ingesting a CHO-rich diet composed of normal food-stuffs (N) could be compared with those obtained after the same diet supplemented with CHO-concentrated liquids. In addition it was decided to study the daily contribution of CHO, fat, and protein metabolism to total energy exchange under these circumstances. The study was performed in a cross-over design with a randomized order of treatment.

**Part I, Normal Diet**

The part of the study in which the subjects received the normal CHO-rich diet will be described and discussed in this article. The effect of dietary manipulation as well as the induced metabolic changes will be discussed in separate articles (5, 6).

The aim of part I was to test the following hypotheses:

- Cyclists having available ad libitum a normal but CHO-rich diet will be able to maintain energy balance and to meet the daily CHO needs even in situations of repeated, high-intensity, sustained cycling exercise.
- Cyclists having available ad libitum ordinary and mineralized drinks throughout the exercise period will be able to compensate for the exercise-induced fluid losses.

**Procedures, Materials, and Methods**

**Subjects**

Thirteen highly trained cyclists participated in this study. Physical characteristics are presented in Table 1.

**Experimental Design**

The subjects were asked not to participate in vigorous training or competition during the 2 days preceding the arrival in the laboratory and to ingest a normal but CHO-rich diet (dietary advice was given by a registered dietician). All subjects were informed about the nature, purpose, and possible risks of the study, before giving their voluntary written consent to participate. The experiment was conducted over 7 sequential days using a semiautomated respiration chamber system.

The subjects reported to the laboratory on Sunday evening (day 1) at 9:00 PM to get accustomed to the chamber. They received a time schedule for all activities in the forthcoming week. On the next preparation day (day 2), a supply of food and fluid of known quantity and composition selected by each subject was made available. It is known that differences in substrate mobilization and utilization may occur depending on diet composition, exercise executed, and quantitative endogenous CHO stores (19–22, 29, 30, 31). For that reason diet composition and amount of exercise was completely controlled during 24 h previous to the experiment (day 2). At least 60% CHO and a minimal protein intake of 1.2 g·kg⁻¹ were assured to realize a complete build up of endogenous substrate pools and to avoid inter individual differences in pre-test nutritional and metabolic status. Protein intake was calculated daily, immediately after dinner. To assure a minimal intake of 1.2 g·kg⁻¹, the subjects were supplemented with a protein concentrate whenever intake was calculated to be too small for that day. This food supply was continuously provided until the end of the experiment on Saturday morning 9:00 AM 6 days later. Food for breakfast, lunch, and in-between meals was supplied at 7:30 AM. However, extras could be obtained throughout the day upon request. Dinner was served at 6:00 PM. There were no quantitative limitations. The cyclists were instructed about the importance of adequate food and fluid intake and were encouraged to eat and drink as much as desired.

Weight and volumes of foods and drinks were measured and registered in a diary allowing for analysis of 24-h intake. The residual amounts were weighed and accounted for in the final calculations. Energy and nitrogen content of all available food items had been previously determined. Actual performance capacity expressed in Watt (Wmax) and maximal oxygen uptake (VO₂max; ml·kg⁻¹·min⁻¹) were determined at 10:00 AM, day 2, during an incremental cycle ergometer test. The experimental schedule is presented in Fig. 1.

The respiration chambers were closed at 04:00 PM on day 2 and measurements for calculation of energy expenditure were started. Blood samples were taken through a specially designed airlock in the respiration chamber wall. The samples were drawn into EDTA evacuated tubes from a Teflon catheter, which was inserted into an antecubital vein at 7:00 AM daily, and was connected with a three-way stopcock. The blood was immediately put in ice water.

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**Table 1: Physical characteristics of experimental subjects**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value (±SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>20.0 ± 2.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.3 ± 1.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.6 ± 1.7</td>
</tr>
<tr>
<td>VO₂max (ml·kg⁻¹·min⁻¹)</td>
<td>65.1 ± 1.2</td>
</tr>
<tr>
<td>Wmax (W)</td>
<td>390 ± 6.0</td>
</tr>
<tr>
<td>Wmax·kg⁻¹ (W)</td>
<td>5.3 ± 0.4</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>12.0 ± 0.8</td>
</tr>
</tbody>
</table>

Mean values ± SEM (n = 13)
Fig. 1: Experimental schedule. On day 2 actual performance capacity (Wmax; W) and maximal oxygen uptake (V\textsubscript{Omax}; ml·min\textsuperscript{-1}) were determined at 10:00 AM using an incremental bicycle ergometer test. Days 3 and 6 were rest days; cycling at 40% Wmax during 45 min at 10:00 AM and 2:00 PM. Days 4 and 5: exercise to exhaustion. Day 7: end of the experiment at 9:00 AM. A muscle biopsy (6) was taken on days 2, 5, and 6. Blood sampling was done at 7:00 AM, 12:00 AM, and 4:00 PM on days 3 to 6.

Fig. 2: Cycling program during days 4 and 5. There was a warming up of 30 min at 30% Wmax, followed by 10 min at 60% Wmax, followed by 9 times by 6 min at 80% Wmax, and 6 min at 60% Wmax. Thereafter, exercise was interrupted to collect blood and sweat samples and was then continued at 80% Wmax for 10 min, followed by 50% and 20 min at 50% Wmax. Exercise intensity was increased to 80% Wmax for 1 min followed by 6 min at 60% Wmax, which was repeated 8 times. Finally, exercise intensity was increased to 90% Wmax which had to be performed to exhaustion.

Body weight (naked) was measured daily with a digital balance accurate to 100 g at 7:00 AM, 12:00 AM, 3:00 PM, and 9:00 PM, respectively.

Rest days were included in the program to determine resting status for comparison with the following two exercise days.

Sweat samples were collected on days 4 and 5 by absorption into pre-dried pads located in water and airlight capsules (28). Sweat capsules were placed in the infraspinous fossa of the scapula 10 min prior to exercise and kept in place by an elastic mesh vest. Exercise was started at 10:00 AM. Eighty percent and 60% Wmax were chosen to mimic cycling ahead of the group of benefitting from wind shielding within the group, respectively. Ninety percent of Wmax (equivalent to approximately 80% V\textsubscript{Omax}) at the end was chosen to simulate a finish on a mountain top. Exercise was stopped when RPM fell below 60/min (Fig. 2).

During exercise, fluids were available ad libitum (tea, coffee, milk, lemonade, and a placebo "sport drink" consisting of artificially sweetened, colored, and mineralized water). Feces and urine were kept at –20 °C in a deep freezer toilet and were collected in 24-h periods.

A percutaneous needle biopsy sample (17) was taken from the m. vastus lateralis at 4:00 PM at rest on day 2, 45 min after reaching exhaustion on day 5, and after 24 h of recovery on day 6. (The biopsy could not be taken immediately after reaching exhaustion because of measurements which had to be finished before the respiration chamber could be opened). The biopsy sample was immediately frozen in liquid nitrogen for analysis of glycogen and triacylglycerol.

**Diet Manipulation**

For diet manipulation the total group of 13 subjects was divided into two subgroups. In six randomly selected subjects the normal diet was supplemented with an
Tab. 2 Energy intake and expenditure

<table>
<thead>
<tr>
<th>Day</th>
<th>Energy</th>
<th>Intake</th>
<th>Expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>19.4 ± 1.1</td>
<td>19.3 ± 0.8</td>
<td>19.5 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>16.1 ± 0.3</td>
<td>28.8 ± 0.8</td>
<td>25.2 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>16.1 ± 0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean values ± 1 SEM (MJ·day⁻¹). Days 1 and 3 were resting days, while days 4 and 5 were exercise days. Statistical significance of differences with respect to the values on day 5 is indicated by *P < 0.001.

Although there is a wide variety of CHO sources, it was specifically decided to use a solution composed of mainly long-chain glucose polymers and a low fraction of fructose, because long-chain polymers may be of advantage to the athlete by means of maximizing CHO intake and absorption, while minimizing risks of gastrointestinal distress (4). A small quantity of fructose was added for reasons of taste to increase palatability. FM was selected for the following reasons: The effect of fructose on insulin secretion is minimal which allows for a better stimulation of lipolytic activity under exercise circumstances compared to mainly glucose which has a strong influence on insulin secretion. The second reason was to compose a CHO solution with a 50% contribution of both glucose and fructose but with a lower osmolality as would be derived from eucaloric sucrose. The supplement, prepared as a 20% (w/v) solution, was made available as follows: Standardized resting days 500 ml during the morning, afternoon, and evening (total supply 1500 ml), exercise days during cycling ad libitum and in the evening after dinner, 1000 ml. The cyclists during N treatment were supplemented with equal amounts of a placebo drink at the same times to rule out psychological effects due to the drink. The placebo was flavored with citrus powder, sweetened with saccharin and cyclamate, and artificially colored. The composition of the drinks is presented in Part 2 (5). The experimental design for all treatments was the same as for N.

Analyses

Energy expenditure was determined using an indirect semiautomated calorimeter as previously described by Schoffeniels et al. (39). Gas flows were measured with a dry gas meter (Dort, NL), oxygen was analyzed using a Servomex paramagnetic oxygen analyzer (Taylor, GB), and carbon dioxide using an infrared CO₂ analyzer (Hartmann and Braun, FRG).

Energy expenditure was calculated according to the formula of Consolazio (9):

\[
E_{m} = 3.78 \text{VO}_{2} + 1.16\text{VO}_{2} - 2.98 \text{Nu}
\]

Where \(E_m\) = energy expenditure (kcal), \(\text{VO}_{2}\) = oxygen consumption in liters, \(\text{VO}_{2}\) = \(\text{CO}_{2}\) production in liters, and \(\text{Nu}\) is the amount of nitrogen excreted in urine in grams, over a measured time.

Daily energy balance was calculated from energy expended and energy intake as calculated from daily food and fluid consumption. Corrections were made for energy losses from feces, urine, and sweat and for the blood samples drawn. Energy content of food, fluid, feces, urine, and blood was determined by bomb calorimetry (IKA, FRG). Energy content from sweat was calculated from total sweat urea, assuming that the remainder is negligible. Total sweat loss was determined from body weight change while accounting for fluid intake, urine production, blood volume loss, and respiratory water loss (32). The sweat volume collected in the capsules was determined by capsule weight changes using an analytical balance (Mettler). Sweat urea content was calculated enzymatically (urease method, Boehringer 396346). Nitrogen content of blood and urine was determined by the chemiluminescence method (Antek, FRG). Daily nitrogen losses were then calculated. The quantitative contribution of CHO, fat, and protein to total daily energy intake was calculated from daily intake records using a UCV computer coding system for Dutch foodstuffs (24, 1). CHO and fat oxidation was calculated from nonprotein respiratory quotient (R).

CHO and fat oxidation was calculated from R. Protein oxidation was calculated from daily nitrogen losses in urine and sweat. From the data gathered, the daily contribution of CHO, fat, and protein to total 24-h energy exchange was determined as well as the relative contribution during exercise was calculated.

Plasma volume changes were calculated from hemoglobin (Hb cyanide method) and hematocrit values, according to Dill and Costill (14).

Statistics

Student's paired t-test was used to compare the data of the first standardized rest day with those of the following exercise and recovery days. For all analyses, the 0.05 level was used as the minimum level of confidence for statistical significance.

Results

Energy Intake

Energy intake (EI) from food and fluid was markedly constant during the whole experimental period despite the fact that exhausting cycling exercise was executed...
on days 4 and 5 of the experiment (Table 3). A small but not statistically significant increase in EI was found during the recovery day.

Energy expenditure (EE) as measured in the respiration chamber was similar on both rest days and increased by more than 60% to 26 MJ/day as a result of exhaustive cycling. This level of EE is equivalent to EE levels previously observed during the Tour de France (38). As a result of the constant EI but strongly increased EE, energy balance was +10 and +8 MJ negative during the exhaustive cycling days, 4 and 5, respectively (Fig. 3, Table 2).
Tab. 4 Fluid intake/loss

<table>
<thead>
<tr>
<th>Day Conditions</th>
<th>Intake 1</th>
<th>Loss 1</th>
<th>Intake 2</th>
<th>Loss 2</th>
<th>Intake 3</th>
<th>Loss 3</th>
<th>Intake 4</th>
<th>Loss 4</th>
<th>Intake 5</th>
<th>Loss 5</th>
<th>Intake 6</th>
<th>Loss 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>REST</td>
<td>4.01 ± 0.19</td>
<td>3.14 ± 0.22</td>
<td>3.50 ± 0.29</td>
<td>3.70 ± 0.25</td>
<td>1.68 ± 0.11</td>
<td>2.81 ± 0.32</td>
<td>0.15*</td>
<td>0.40*</td>
<td>0.50*</td>
<td>3.18 ± 0.16</td>
<td>3.50 ± 0.25</td>
<td>3.17 ± 0.20</td>
</tr>
<tr>
<td>Urine</td>
<td>1.81 ± 0.19</td>
<td>0.15*</td>
<td>0.32*</td>
<td>0.40*</td>
<td>3.00 ± 0.16</td>
<td>0.55 ± 0.02</td>
<td>0.52 ± 0.02</td>
<td>0.50*</td>
<td>0.60*</td>
<td>0.50*</td>
<td>0.50*</td>
<td>0.60*</td>
</tr>
<tr>
<td>Faces</td>
<td>0.15*</td>
<td>0.15*</td>
<td>0.32*</td>
<td>0.40*</td>
<td>3.50 ± 0.25</td>
<td>0.55 ± 0.02</td>
<td>0.52 ± 0.02</td>
<td>0.50*</td>
<td>0.60*</td>
<td>0.50*</td>
<td>0.60*</td>
<td></td>
</tr>
<tr>
<td>Resp. water</td>
<td>0.40*</td>
<td>0.32*</td>
<td>0.40*</td>
<td>0.40*</td>
<td>3.50 ± 0.25</td>
<td>0.55 ± 0.02</td>
<td>0.52 ± 0.02</td>
<td>0.50*</td>
<td>0.60*</td>
<td>0.50*</td>
<td>0.60*</td>
<td></td>
</tr>
</tbody>
</table>

Mean values ± 1 SEM (n = 13). Fluid loss from sweat and respiratory water was not calculated on the rest days (3 and 6). * = mean daily loss under resting conditions taken from Wiltz (38).

**Nutrient Intake**

CHO and protein intake levels – 62.5 En% and 12.5 En%, respectively – were comparable to those observed during the Tour de France (38). The relative contribution of CHO, protein, and fat to total EI also remained constant (Figs 4 and 5), except for the recovery day when CHO intake increased significantly to 70 En%.

The absolute amount of CHO and protein intake (g) increased during the recovery day as a result of increased food intake.

**Nutrient Oxidation**

The amount of CHO and protein oxidized have also been plotted in Figs. 4 and 5. CHO, fat, and protein oxidation were estimated from the calculated R and the measured nitrogen excretion urine and sweat. A comparison with the intake of these nutrients revealed that CHO intake was greater than CHO oxidation on both rest days, while oxidation exceeded intake on the first exercise day, was similar to intake on the second exercise day, and significantly smaller during the recovery day. Protein oxidation, as calculated from N loss in sweat and urine was less than recovery day protein oxidation, increased significantly, almost balancing protein intake. The mean levels of intake and oxidation both exceeded 1.5 g·kg⁻¹·BW. The daily relative contribution of CHO, protein, and fat to energy expenditure is presented in Fig. 6.

During the rest day CHO had the largest contribution to energy metabolism (58.2% ± 6.1%). This contribution decreased gradually and significantly on days 4 and 5 (51.4% ± 3.1% and 40.6% ± 3.4%, respectively) whereas it remained significantly lower during the recovery day (55.3% ± 4.0%) compared with day 3.

Concurrently the contribution of fat to total energy supply gradually increased. The percentage contribution of protein decreased significantly on the first exercise day from 9.5% ± 0.7% to 7.1% ± 0.5%, and remained unchanged on the second exercise day (8.2% ± 0.7%). A significant increase occurred during the recovery day (14.6% ± 1.3%) compared with day 3. Calculation of the relative contribution of CHO, fat, and protein during the sustained exercise period on days 4 and 5 revealed a highly significant increase in fat and decrease in CHO metabolism on day 5 compared with day 4 (Table 3). The quantitative relative contribution depended largely on the level of energy expenditure so that the figures obtained at rest and during exercise were quite different. This difference was most pronounced with respect to protein.

**Food Consumption Pattern**

Analysis of the daily consumption pattern showed that the contribution of main meals (breakfast, lunch, dinner) to total energy intake amounted to 65.7%–69.5% on the different experimental days. There was no significant difference between rest and exercise days. The in-between meal food consumption accounted for 30.5%–34.3% of total energy intake. This eating pattern remained markedly constant throughout the experiment (Fig. 7).

**Fluids**

Daily fluid intake and loss at rest and during exercise periods is presented in Table 4. As a result of fluid intake during exercise, total fluid intake increased to more than 6 L/day. Fluid intake at rest remained about the same over the whole period (3–4 L/day). Fluid intake during exercise...
Table 5: Body weights over 5 days

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7:00 AM</td>
<td>73.7 ± 2.2</td>
<td>75.4 ± 2.3</td>
<td>72.5 ± 2.2</td>
<td>72.4 ± 2.1</td>
<td>72.8 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>4:00 PM</td>
<td>73.7 ± 2.3</td>
<td>72.9 ± 2.3</td>
<td>72.9 ± 2.1</td>
<td>72.7 ± 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8:00 PM</td>
<td>74.7 ± 2.3</td>
<td>73.4 ± 2.2</td>
<td>73.1 ± 2.2</td>
<td>73.0 ± 2.2</td>
<td></td>
</tr>
</tbody>
</table>

Mean values ± SEM (kg; n = 13) significant changes with respect to initial values on day 3 are indicated by: *P < 0.01; **P < 0.001. Days 3 and 6 were rest days, days 4 and 5 were exhausting exercise days.

Exceeded 3 l/day; sweat loss and respiratory fluid loss approximated 4 l/day (Table 4). Mean urine production increased on both exercise days compared with the rest days.

On both rest days plasma volume, as a reflection of the hydration status of the blood, showed a significant increase at 12:00 and 4:00 PM compared with 7:00 AM on the first day. This increase was not observed on either of the following exercise days. The increase during the recovery day was significantly greater than during the first rest day (Fig. 8).

Body weight significantly decreased during the exercise days and increased somewhat during the following 1 1/2 days of recovery (Table 5). However, final body weight was still significantly lower than initial body weight.

Discussion

The results show that total energy intake exceeded total energy output whenever the cyclists had an active rest day. When competitive cycling comparable to a hard day in the Tour de France (3) was simulated, the cyclists showed a marked constancy in energy intake. Although they were all aware of the importance of adequate food intake, they were not able to ingest sufficient food to compensate for the increased energy expenditure.

Because the setup of the experiment was such that food and drink were available ad libitum within reach throughout the day, the reason for this maladaptation of energy consumption was most probably due to a suppressed appetite and/or intolerance of the gastrointestinal tract to bear and digest large bulk loads of food while exercising. Moreover, the cyclists indicated that the exercise was too intensive to be able to ingest large amounts of food and/or they were too exhausted to eat. As a result, there was no change in quantitative food intake during both exercise days compared with the foregoing rest day.

The nibbling eating pattern and in-between meal snacking (16, 25, 41) was also present in this study. In-between meal snacking represented 30%-34% of the total energy intake in these cyclists, the majority of which took place in the evening. This may be explained by a continuous hunger for small, CHO-rich snacks.

Although we expected that energy consumption during the evening would be increased after intensive cycling, to compensate for the increased energy expenditure, we did not see such a compensation. There tended to be what might be called a "voluntary energy depletion" which finally led to a slightly but not significantly increased energy intake and a significantly increased CHO intake (70 En%) during the following recovery day, indicating a preference for CHO-rich foods. As a result, energy balance was positive on the active rest days but significantly negative during the exercise exhaustion days (Fig. 3). CHO had a large contribution to energy production on the first cycling day most probably because exercise intensity was greater than 50% of VO2 max. On that day CHO intake was insufficient to meet the needs, as indicated by the difference between CHO intake and calculated CHO oxidation (Fig. 4). This relatively low CHO intake can to a large extent be explained by the negative energy balance. The reason is that CHO contributed to the largest fraction of total energy intake whereas on the other hand CHO also contributed to the major fraction in energy expenditure during exercise. As a result of this CHO imbalance, endogenous CHO must have contributed considerably to energy production. In the case of endogenous CHO depletion, the body will adapt with enhanced fat mobilization and gluconeogenesis (34, 37). It has been shown that enhanced availability of free fatty acids increases the fraction of oxidized fat and decreases CHO oxidation because both substrates act competitively at the site of transport across the muscle cell membrane and subsequent oxidation (7, 18, 23, 34, 36). This may explain the increased fat oxidation on the second exercise day and consequently the smaller CHO contribution (Table 3, Fig. 6).

Protein intake per kg body weight was more than adequate according to RDA standards (1.7 vs 0.8 g kg^-1 RDA (33)). However, the calculated fraction of protein, involved in energy exchange, indicated that during both exercise days and the following recovery day, when protein oxidation...
was significantly increased (Fig. 6), protein intake almost equaled protein loss [N balance is described elsewhere (6)].

In this situation of stressful exercise and negative energy balance, protein oxidation per kg body weight was far in excess of the amount of protein intake advised by the National Research Council (RDA). The amount of protein oxidized indicated that even 1.5 g·kg⁻¹ in these circumstances may not be sufficient to meet the needs. Increased protein degradation as an indication of energy depletion and catabolic status of the body is supported by Lemon and Mullin (30) who showed that CHO-depleted subjects had a significant increase in protein breakdown compared with CHO-loaded subjects. Recently, Lemon (27) suggested a protein requirement of 1.2 to 1.6 g·kg⁻¹·day⁻¹.

Fluid intake appeared to be sufficient to meet the requirements both during rest and exercise days. The fact that plasma volume increased during day 3 may be explained by changes in blood composition due to absorption of nutrients, electrolytes, and water during the day. That this did not occur during the exercise days may be indicative of the smaller fluid overload (fluid intake - fluid loss) due to severe sweating on these days, compared with both rest days, or to fluid shifts within the body. The fact that urine volumes increased during the exercise day indicated a stimulus to water excretion from the body rather than to retain it. Some of the subjects had to urinate during the cycling sessions. Furthermore, indicative of an adequate fluid supply also during exercise is the observation that plasma volume did not fall below the initial "zero" value as measured at 7:00 AM after an overnight fast on the first standardized rest day. It has to be kept in mind, however, that plasma volume due to changes in osmolality may not necessarily reflect the tissue hydration status. Thus, it may well be that tissue dehydration has taken place at the cost of maintaining a normal plasma volume especially during day 4 when fluid loss exceeded fluid intake by approximately one liter. During the recovery day, plasma volume increased significantly above the values of the first rest day, which may be explained by sodium and water retention which has been shown to occur after periods of severe prolonged sweating (11).

In summary the results lead to the following conclusions:

- When prolonged intensive cycling increases energy expenditure to levels above a certain threshold (probably around 20 MJ), athletes are unable to consume enough conventional food to provide adequate energy to compensate for the increased energy expenditure.

- A sport-adjusted, CHO-rich diet (> 60 Em% CHO) is in itself no guarantee that CHO intake will be sufficient during days of hard, long-lasting exercise.

- Drinking 0.75-1.1 l·h⁻¹ is sufficient to maintain a normal plasma volume during prolonged intensive cycling under situations as in this study (ambient temperature 20 °C ± 2 °C, relative humidity 65%-75%).

- Protein requirement in the exercise circumstances described is greater than 1.5 g·kg⁻¹ body weight/day.

References