Physiological, metabolic, and performance implications of a prolonged hill walk: influence of energy intake

PHILIP N. AINSLIE,1 IAIN T. CAMPBELL,2 KEITH N. FRAYN,3 SANDY M. HUMPHREYS,3 DONALD P. M. MACLAREN,4 AND THOMAS REILLY4

1Department of Physiology and Biophysics, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada T2N 4N1; 2University Department of Anaesthesia, Withington Hospital, University Hospitals of South Manchester, Manchester M20 2LR; 3Oxford Lipid Metabolism Group, Radcliffe Infirmary, Oxford OX2 6HE; and 4Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool L3 2ET, United Kingdom

Submitted 25 July 2002; accepted in final form 21 October 2002

Hill walking is an activity that is likely to entail both high energy expenditure and a large involvement from recreational participants. The high overall energy expenditure is due to the prolonged nature of the activity (1). An important and unique consideration is that hill walking is a recreational activity that attracts a wide range of participants with varying age and fitness levels.

Address for reprint requests and other correspondence: P. N. Ainslie, Dept. of Physiology and Biophysics, Univ. of Calgary, Faculty of Medicine, Heritage Medical Research Bldg., Rm. 232, 3330 Hospital Dr. NW, Calgary, AB, Canada T2N 4N1 (E-mail: painslie@ucalgary.ca).

The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked “advertisement” in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
In a recent study (1), unremarkable changes in reaction time (cognitive function), mood state, and grip strength were evident after a 12-km strenuous hill walk. The data from this study suggest that, despite serious physiological stress, the subjects demonstrated normal motor control during the walk. Furthermore, in a questionnaire-based study (3), based on 100 hill walkers, a weak but significant relationship was identified between subjects consuming a low-energy intake and exhibiting an increased incidence of injury. In addition, the results from the questionnaire indicated normal distances covered of 18–26 km over 6–8 h in duration. Such distance and duration will likely entail large energy expenditures and will potentially elicit a large deficit in energy. The implications of such an acute energy deficiency on recreational participants remain unclear and have not been investigated in this context.

The results from the previously mentioned studies (1, 3) suggest that a large number of hill walkers may be undertaking the activity with relatively low-energy intakes and subsequently sustaining high-energy deficits. Surprisingly, the influence of differing energy intake per se has not been established on recreational participants.

The purpose of the present study therefore was to determine the effects of two different energy intakes on some relevant responses that are important to the safety of hill walkers, such as the potential thermal stress, impaired psychomotor performance, and the ability to maintain glycemia. We aimed to extend our previous investigations into a hill-walking event over a more prolonged period than considered in our initial study (1). On the basis of the previous studies, we postulated that, because of the large energy cost of such hill-walking events, subjects receiving a low-energy intake might be more prone to compromises in performance than their counterparts receiving a high-energy intake. Furthermore, as evident in previous studies conducted on very prolonged exercise, combined with low-energy intakes (10, 37, 28), it was hypothesized that the low-energy intake stimulates metabolism in such a way that blood glucose concentrations are maintained, mediated via an increased mobilization of fat.

**METHODS**

**Subjects**

Sixteen male subjects participated in this study. All subjects were given both verbal and written instructions outlining the experimental procedure, and written informed consent was obtained. The study was approved by the Human Ethics Committee of Liverpool John Moores University. The physical characteristics of the subjects are shown in Table 1.

<table>
<thead>
<tr>
<th>Physical characteristics of the subjects</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>24 ± 3</td>
<td>19–29</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.79 ± 0.08</td>
<td>1.70–1.86</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>76.3 ± 11.8</td>
<td>62–94</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>24.6 ± 2.3</td>
<td>18–27</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>16.2 ± 5.3</td>
<td>5.4–26</td>
</tr>
<tr>
<td>VO_{2peak}, ml.kg⁻¹.min⁻¹</td>
<td>51.8 ± 8.5</td>
<td>45–64</td>
</tr>
</tbody>
</table>

Values are based on 16 subjects. BMI, body mass index; VO_{2peak}, peak oxygen uptake.

**Protocol and Procedures**

In a balanced design, subjects completed a 21-km hill walk under two different dietary conditions. The course varied in elevation from 100 to 902 m above sea level and consisted of a range of gradients and terrain typical of a mountainous hill walk. A cottage was used as a temporary field laboratory and for living accommodation, and it was located at the start and end of the hill walk. Subjects woke each morning between 0500 and 0530 and completed the preliminary experiments before the hill walk. Self-paced walking began each day between 0700 and 0800. Subjects were instructed to record their nude body mass each morning before consuming any food or beverages and after voiding, with calibrated balance scales accurate to 0.1 kg, and immediately on completion of the walk. After the initial weighing and preliminary tests, the participants inserted a rectal temperature probe to a depth of 10 cm beyond the anal sphincter. The rectal probe was connected to a data logger (Squirrel meter 1000, Grant Instruments, Cambridge, UK) that recorded data every 6 min. During the walk, a rest period of 1–5 min was allowed approximately every 3.5 km where subjects had an opportunity to consume their food and fluid, and a 15-min stop was allowed at approximately halfway through the course. In addition, at these time points, environmental temperature measurements were made, as described previously (1). All subjects carried a lightweight waterproof backpack that contained spare clothing, food and water supply for the walk, and the data logger described above. The loaded pack weighed ~9.5 kg, which is consistent with a hill-walking scenario.

**Diet**

Subjects were asked to fast from 2000 until waking and then consume a standardized breakfast of 2.5 MJ (595 kcal). For the duration of the hill walk, subjects were then given either a high- or low-energy diet in a balanced design. The diets were divided into three equal amounts, and subjects were encouraged to consume one amount by 7 km, one by 14 km, and the final amount by 21 km. The constituents for both the diets were chosen from a range of snacks that included commercially available products such as biscuits, chocolate bars, flapjacks, and cheese sandwiches. In both conditions,
subjects were instructed, and monitored by the same investigator, to consume ~400 ml/h of water. The total energy intake on the high-energy intake diet was 12.7 MJ (3,019 kcal), compared with 2.6 MJ (616 kcal) on the low-energy diet. Both diets had similar macronutrient distribution, as given in Table 2. The low-energy intake was based on the results from previous studies (1, 3).

**Measurements and Analysis**

**Temperature, heart rate, and environmental conditions.** Rectal temperature, heart rate, and environmental conditions were monitored continuously and recorded as described previously under similar testing conditions (1). Because of technical problems during the walks, where the data-logging system malfunctioned, the rectal temperature data are based on 14 subjects.

**Performance measurements.** In the morning, before walking, and immediately on completion of the hill walk, subjects completed a battery of psychomotor and performance tests that included Profile of Mood States (1, 38), subjective ratings, single and choice reaction time (perception task and cognitive processing time), flexibility, dynamic and static balance, kinesthetic differentiation grip, and leg strength (muscular power) tests. The subjects were fully familiarized with the use of the equipment, and each test was performed three times in a balanced fashion. The reliability and test-retest reproducibility of these tests have been recently described (43), and they were performed in the following order.

**Reaction time tests.** Reaction time tests (Hick’s law) (1-, 2-, 4-, and 8-choice reaction time for a finger response) were assessed on a laptop computer. The one- and two-finger reaction time test was considered to be a perception task, whereas the four and eight-finger reaction time was considered to be a decision-making task (45).

**Flexibility.** Flexibility was measured by using conventional “sit and reach” test following guidelines by the American College of Sports Medicine (6). Participants sit and bend their trunk forward with their knees fully extended. The distance reached with the tip of their middle finger on a scaling box was recorded.

**Dynamic balance (tandem walking forward and backward).** Subjects walked along a line 6 m in length. Subjects placed one foot in front of the other with heel and toe of their shoes touching and walking as fast as possible without making mistakes or side touches. The best result (time in s) of three trials was recorded.

**Static balance.** Subjects stood on one foot with eyes open and arms relaxed by sides. The heel of the opposite foot was placed against the medial side of the supporting leg at the level of the knee joint while the thigh was kept rotated outward. The number of restarts, over a 60-s period, was recorded.

**Kinesthetic differentiation (standing broad jump).** Distances of 50, 75, and 100 cm, marked by line, were used in this test. Each jump started at a line, with the subjects jumping the distances and landing on the exact mark. The accuracy of the jumps was assessed according to the participant’s heel, which should be placed as close to the line as possible. Distance was recorded from the determined distance line.

**Grip and leg strength and jump tests (motor function).** Motor function was assessed by means of a handgrip dynamometer (Taki, Narragansett, Japan). In addition, muscular power was assessed by means of a leg dynamometer (Takei Scientific Instruments, Tokyo, Japan). Vertical jump (strength and muscular power) performance was assessed by the ability to perform a maximal jump from an electronic force platform and also by the maximal jump a subject could make from a stationary line.

**Blood and urine sampling and analysis.** Blood samples were obtained from subjects in a semireclined position before and immediately on completion of the walk. Blood samples were drawn into 10-ml heparinized syringes. A portion (20 μl) was used immediately for the measurement of hemoglobin in duplicate (Hemocue B-hemoglobin photometer, Hemocue, Sheffield, UK) and packed cell volume (conventional microhematocrit method). Plasma volume changes were calculated from changes in hemoglobin and packed cell volume relative to initial resting values as described by Dill and Costill (16). From the remaining blood, plasma was separated rapidly at 4°C and frozen for later determination of plasma glucose, nonesterified fatty acids (NEFA), and triacylglycerol (TAG) concentrations by enzymatic methods using kits (glucose, TAG: Randox Laboratories, Crumlin, UK; NEFA, WAKO, Alpha Laboratories, Eastleigh, UK). In addition, a portion of the plasma was deproteinized with perchloric acid (7% wt/vol) in preparation for plasma glycerol and 3-hydroxybutyrate (3-OHB) determination by enzymatic methods, as described by Coppack et al. (13). All enzymatic methods were adapted to an IL Monarch centrifugal analyzer (Instrumentation Laboratory, Warrington, UK). Plasma insulin concentrations were determined with a double-antibody radioimmunoassay, and plasma growth hormone concentration was determined by using a two-site immunoradiometric assay (Pharmacia and Upjohn, Milton Keynes, UK). Plasma cortisol concentrations were determined by using a solid-phase radioimmunoassay (Diagnostic Products, Llanberis, Wales, UK). All samples for the hormone analysis were frozen according to the instructions of the manufacturers of the kit and then batch analyzed; the inter- and intra-assay coefficient of variation was <8%.

An index of dehydration was determined in triplicate by using urine osmolality determined by freezing-point depression [Advanced Micro-osmometer (model 3300), Vitech Scientific, West Sussex, UK]. For the urine osmolality, a 5-ml sample was produced after the first void of the day and then from the first sample after the walk.

**Statistical analysis.** Variables are presented as means ± SD. Data were initially tested for normality before being analyzed by a two-way repeated-measures ANOVA. The ANOVA results were corrected by the Huynh-Feldt ε-adjusted degrees of freedom when the violation to sphericity was minimal (>0.75), and the Greenhouse-Geisser correction

### Table 2. Total composition of test meals

<table>
<thead>
<tr>
<th></th>
<th>High-Energy Intake</th>
<th>Low-Energy Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat, g</td>
<td>135</td>
<td>26</td>
</tr>
<tr>
<td>%Saturated</td>
<td>41</td>
<td>39</td>
</tr>
<tr>
<td>%Energy</td>
<td>39</td>
<td>38</td>
</tr>
<tr>
<td>CHO, g</td>
<td>401</td>
<td>74</td>
</tr>
<tr>
<td>%Simple</td>
<td>54</td>
<td>56</td>
</tr>
<tr>
<td>%Energy</td>
<td>51</td>
<td>52</td>
</tr>
<tr>
<td>Protein, g</td>
<td>74</td>
<td>15</td>
</tr>
<tr>
<td>%Energy</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total energy MJ</td>
<td>12.7</td>
<td>2.6</td>
</tr>
<tr>
<td>kcal</td>
<td>3,019</td>
<td>616</td>
</tr>
</tbody>
</table>

Both diets had similar proportions of simple sugars relative to total carbohydrate (CHO), and both had similar saturated-to-unsaturated fatty acid ratio values.
used when sphericity was violated (<0.75) and significant condition and condition-time interactions were identified (22). Post hoc tests (Tukey’s) were performed to isolate any significant differences. Student’s paired t-tests ascertained between-condition differences when a variable was measured once. For data that were not normally distributed, the Kruskal-Wallis test followed by the Wilcoxon matched-pair signed-rank test where appropriate was used for analysis. Statistical significance was set at $P \leq 0.05$ for all statistical tests.

**RESULTS**

**Exercise Duration, Weather, And Diet Compliance**

All subjects completed the 21-km hill walk. The mean (range) duration for the hill-walk was 7 h and 28 min (5 h and 51 min to 10 h and 56 min). There were no differences between the different energy conditions in time to complete the walk. The differences in the time to complete the walk were due mainly to variations in weather conditions and terrain. Ten subjects experienced very sustained wet and windy weather during both of their walking conditions. During a number of these adverse conditions, wind speeds of up to 100 km/h were recorded. Little snow or ice was encountered as a result of the wet and relatively mild conditions. During the high-energy intake, three of the subjects had difficulties in consuming all of the food. The amount of unconsumed food was <1.4 MJ per person. Because this amount was <10% of the required intake, data for these subjects were included in subsequent analysis. All subjects consumed all the food on the low-energy diet.

**Thermoregulatory and Heart Rate**

Although there was a clear trend of a lowered rectal temperature during the low-energy intake conditions, this did not reach statistical significance at any time point. However, when comparing the 10 subjects who experienced sustained wet and windy conditions on both dietary conditions, a significant difference between the high- and low-energy intake conditions ($P < 0.05$) was evident at each measurement point during the last 9 km of the walk (Fig. 1). A number of the subjects in each of the low- and high-energy intake conditions exhibited marked decreases in rectal temperature. One subject’s rectal temperature fell below 35°C; after warming and monitoring, his rectal temperature increased rapidly to normal levels and he sustained no subsequent ill effects. It was noteworthy that the subjects completed their walks in sustained wet and windy weather and, although they were adequately dressed for the conditions, they were all very lean individuals with an estimated percent body fat <8%. No between-group differences were evident in the heart rate responses (data not shown). The mean heart rate for the duration of the walk was 132 ± 19 and 135 ± 21 beats/min in the high and low-energy intakes, respectively.

**Fig. 1.** Mean rectal temperature results from the subset of subjects who completed the hill walk, under both energy intake conditions, in sustained wet and windy weather. Values are means ± SD; $n = 10$ subjects. Significant between-group difference: *$P < 0.05$; **$P < 0.01$.

**Performance Responses**

Table 3 gives the results from the measured performance tests. The only statistical differences between the different energy intakes were evident in the reaction time and balance tests. The high-energy intake group showed an improved ($P < 0.05$) reaction time in both one- and two-finger reaction time, whereas no change was displayed in the low-energy intake or in four- and eight-finger reaction time tests in either group. The high-energy intake group displayed no change in the balance tests. Conversely, in the low-energy intake condition, a deterioration of both forward ($P < 0.01$) and static balance ($P < 0.05$) was evident when compared with prewalk values.

**Subjective Observations**

During the low-energy intake condition, 9 of the 16 subjects showed marked changes in behavior during the walk. These changes were especially evident after the first 10 km. The majority of these subjects showed marked signs of withdrawal from voluntary conversation, slowing down in pace, and, in four cases, aggressive and negative behavior. These symptoms are generally considered as some of the early signs and symptoms of exposure and of hypoglycemia. Incidentally, these signs and symptoms were present predominately in combination with adverse, wet, and windy weather conditions. Furthermore, four of the subjects on the low-energy intakes sustained minor injuries during the walk. These injuries were muscular in three subjects, who still managed to complete the walk. One subject had to be evacuated from the mountain early because of potential tendon damage in the knee resulting from a slip during a downhill section at ~8 km into the walk. This subject still walked another 5 km after the accident, and the data, where suitable, have been included in the final analysis.
**Blood and Urine Constituents**

There were no significant changes in plasma volume during the walk. Consequently, circulating concentrations have not been corrected for hemoconcentration. Figures 2 and 3 give the concentrations of the blood constituents measured before and immediately after the walks. The general changes in blood metabolism were an increased mobilization of fat and a greater hormonal “stress” response, during the low-energy intake condition. During the low-energy intake, insulin concentrations were suppressed ($P < 0.001$) immediately after the walk compared with prewalk values, whereas on the high-energy intake, the insulin concentrations were significantly elevated on completion of the walk. The NEFA, 3-OHB, and glycerol concentrations were all significantly elevated, immediately after the walk compared with prewalk values, whereas on the high-energy intake, the plasma concentrations of growth hormone and cortisol when compared with the high-energy intake trial showed significantly higher concentrations of growth hormone and cortisol when compared with activity under the high-energy intake condition. During the high-energy intake, the plasma TAG concentrations were significantly elevated from both prewalk values and from that of the low-energy values. Although the blood glucose concentrations were significantly lowered immediately after the walk, during the low-energy intake condition, no subjects became hypoglycemic (blood glucose concentration <3 mmol/l), although the occurrence of hypoglycemia during the walk cannot be ruled out. Urine osmolality decreased from the morning concentrations (535 ± 132 and 523 ± 142 mosmol/kgH2O) to that collected on completion of the walk (188 ± 102 and ± 191 ± 81 mosmol/kgH2O; $P < 0.001$) in the high- and low-energy intake group, respectively.

**DISCUSSION**

The present study has yielded a number of important findings. First, during the low-energy intake, mean blood glucose concentrations leveled off at the low-middle range of normoglycemia whereas, on the high-energy intake, they were significantly elevated compared with the low-energy intake. The maintained blood glucose levels were most probably mediated via an increased mobilization of fat in the low-energy group, sparing glucose utilization by muscle, whereas in the high-energy intake, fat mobilization was suppressed and carbohydrate (CHO) utilization was promoted. Second, the demanding nature of the walks was reflected in some impairment in the measured performance tests. The low-energy group showed modest impairments in performance. Specifically, although the high-energy group exhibited an improved one- and two-finger reaction time during the walk, this was not observed in the low-energy group. Similarly, tests of balance revealed a significant impairment in balance in the low-energy group compared with prewalk values, whereas balance was unaltered in the high-energy group. Finally, the data on temperature regulation suggest that subjects receiving a low-energy intake may be somewhat compromised in their ability to maintain their body temperature when compared with their counterparts consuming a high-energy intake. The mechanism(s) by which a low-energy intake may compromise thermoregulatory ability are unclear.

**Levels of Energy Expenditure**

Previous data obtained in similar investigations, utilizing the doubly labeled water technique (2), over 10 days of hill walking showed that hill walks of similar intensity induce an energy requirement estimated to be between 18.5 and 25.5 MJ/day. Moreover, in an
initial study (1), subjects covered the exact 8 km of the walk used in the present study before descending for 5 km. During this initial study, average energy expenditures of 14.5 MJ for the walk, recorded via continuous measurement of respiratory gas exchange by means of indirect calorimetry, were recorded (1). Because the present study extended the walk of the previous research (1) by a further 8 km of strenuous walking, it is reasonable to estimate that the energy expenditure exceeded 20 MJ for the walking period.

**Effect on Performance**

The main result of the present study was that the high-energy intake group had an improvement in one- and two-finger reaction time (perception task indicator), whereas there was no change in the low-intake group. Choice reaction time (4 and 8 finger) was unchanged in both groups. The influence of different energy intake on cognitive performance has been previously described in relation to CHO ingestion during prolonged exercise. Previous studies have investigated the effects of CHO-electrolyte feeding on cognitive performance after prolonged exercise lasting >1 h, and results have been quite diverse. For example, Reilly and Lewis (42) have shown that CHO ingestion improves cognitive performance in a 120-min cycling task at 60% \( \dot{V}O_2 \text{max} \), whereas Ivy et al. (32) failed to observe any effect of CHO ingestion on reaction time responses after 150 min at 40% \( \dot{V}O_2 \text{max} \). In a recent study, Collardeau et al. (12) showed that CHO-electrolyte ingestion during a 100-min run resulted in an improvement in choice reaction time, compared with a placebo group. Single-reaction time, a perception task indicator, was unchanged in both conditions (12).
One unanticipated result in the present study is that there was no change in choice reaction time (cognitive processing), kinesthetic differentiation, or physical performance (maximal leg and grip strength, maximal jump, and flexibility) after the 21-km hill walk, when a decrement associated with “fatigue” might have been expected, especially in the low-energy intake group. There could be several explanations for the stability of these variables. First, although a negative effect of exercise on cognitive performance is often suggested in the literature (12), through the action of some physiological mediators that are influenced by exercise (21), experimental results have not confirmed this hypothesis, and it is difficult to prove the influence of these mediators on cognitive and physical function during exercise (46). One further possibility is that the physiological fatigue induced by a 21-km hill walk is not great enough to produce a decrease in mental performance or in the other unchanged performance tests. As pointed out by Tomporowski and Ellis (47), the effect of fatigue could be modified by a positive effect of the exercise-induced increase in arousal or of incentive variables. In support of this exercise-induced increase in arousal was the six- to sevenfold increase in ratings of vigilance, assessed by using the Profile of Mood States questionnaire (data not shown). Thus, even during exhaustive exercise, subjects may be able to compensate for the otherwise negative effect on cognitive performance.

Although the impairment in the low-energy intake compared with the high-energy intake condition was moderate, this impairment may well be an influencing factor in susceptibility to both fatigue and injury in the mountainous environment. A relevant observation was that four of the subjects on the low-energy intake sustained minor injuries during the walk. Although it is somewhat circumstantial to identify the exact cause of these injuries because they occurred in severe weather conditions, no injuries occurred in the high-energy intake group over these weather conditions. There is some evidence that low muscle glycogen levels, as may be anticipated during the low-energy intake, are associated with increased injury risk in alpine skiing, especially in recreational skiers (20). The explanation is that glycogen depletion of the fast-twitch fibers will limit the ability to develop a high muscle tension in a short period of time (needed to correct false turns or inadequate timing) (14). Physical inability to correct movements will in time lead to increased injury risks (14). This relationship between low muscle glycogen levels and a physical inability to correct movements could well be mediated through balance impairment. In the present study, this balance impairment was evident only in the low-energy intake condition. Although a failure to provide adequate fuel to sustain the activity may be one factor influencing the susceptibility to injury, the potential mechanisms by which this may occur are unclear but may also be centrally mediated.

Thermoregulatory Responses

The observations of the present study regarding the thermal stresses involved in a hill-walking event, with different energy intakes, have provided some novel results. When comparing the 10 subjects who experienced sustained wet and windy conditions on both dietary conditions, a significant difference between the high- and low-energy intake conditions (P < 0.05) was evident during each measurement point during the last 9 km of the walk. The reasons for this lowered temperature are not clear. All experiments were conducted in a balanced design, which prevented any single effects of weather alone. All experiments were conducted in a balanced design, which prevented any single effects of weather alone. Furthermore, subjects were measured in pairs, each under a different dietary intake. Although the subjects on the high-energy intake may have some advantage from the thermogenic effect of a greater food intake, which may reflect a
small increase in whole body metabolism, this would probably be marginal due to the thermogenic effect of exercise and the relatively small amount of food consumed. One possibility may be that the subjects on the high-energy intake had to stop more frequently to consume food. At these time points, for logistical and safety purposes, the subjects on the low-energy intake also stopped. During these stops the subjects on the low-energy intake were stationary, whereas the subjects consuming the high-energy intake were more active, inasmuch as they had to remove their rucksacks, locate and consume their food, replace rucksack, and then move on. Because heat loss is likely to occur rapidly at this point, this potential to lose heat may be one contributory factor to the lowered rectal temperature in subjects consuming the low-energy intake in adverse conditions.

Another tentative explanation, for the lowered blood temperature, is that the lowered blood glucose in the low-energy intake group caused an earlier increase in peripheral blood flow and therefore evaporative heat loss (25, 36). Evidence suggests that the magnitude of this response depends on the severity of the hypoglycemia (26). A recent investigation by Weller et al. (48) showed that a 36-h fast, compared with a fed control group, caused only a small reduction in rectal temperature over 360 min of intermittent walking in a wet and windy environment in the laboratory. It was concluded that the severity of the environmental conditions would be the limiting factor for exercise performance, irrespective of short-term fasting (48). Conversely, the results from the present study would suggest that both adverse climatic conditions and low-energy intakes will be additive in limiting the ability to operate in such climatic conditions. The differences in the results may be related to the field conditions that would likely impose additional stresses not encountered during simulated conditions of the laboratory. Further work into this area may have important implications for the development of hypothermia in the mountainous environment. One relevant project, via the use of use of portable indirect calorimetry systems, would be to address the question of why/how does a low-energy intake predispose a person to hypothermia. Such an investigation, as utilized in a recent study (1), could measure continuous respiratory gas exchange in subjects on both levels of energy intake to determine whether low-energy intake reduces energy expenditure and thus metabolic heat production.

**Effect on Blood Metabolism**

This maintenance of blood glucose concentrations became possible because of a series of metabolic adaptations geared to meeting the requirements of glycolytic tissues. Insulin secretion is known to decrease during short and prolonged fasting (8), as well as during exercise (7, 24, 40). In the present study, insulin responded rapidly to the combined stimuli of low-energy intake and exercise, declining to <50% of its initial concentration, thus enabling lipolytic and proteolytic processes to be initiated as part of gluconeogenesis. This lowered insulin was also reflected in a marked fat mobilization, characterized by a two- to fivefold increase in NEFA, 3-OHB, and glycerol concentrations. Enhanced fat mobilization should make it easier to maintain blood glucose by decreasing CHO oxidation and promoting gluconeogenesis (5, 37), thus sparing glucose utilization by muscle. Conversely, during the high-energy intake the reverse was evident; insulin levels were increased, which would be expected to lead to a decrease in adipose tissue lipolysis as reflected in the suppressed NEFA, 3-OHB, and glycerol concentrations, compared with the low-energy intake. The large amount of CHO intake (401 g) consumed during the high-energy intake condition would be expected to decrease the amount of energy derived from fat oxidation and increase proportionally the amount of energy derived from blood glucose (4, 34). The resulting effect of this suppressed fat mobilization would alter the metabolic milieu in the favor of CHO utilization in the muscle.

In summary, the data suggest that subjects consuming a low-energy intake may become compromised in their ability to operate safely in the mountainous environment. Although the impairment in the low-energy intake compared with the high-energy intake was somewhat moderate, this impairment may well be an influencing factor in susceptibility to both fatigue and injury while outdoor recreational activity is pursued.

The subjects in this study deserve our special thanks. We admire their bravery to volunteer and the enthusiasm, humor, and persistence they maintained, despite the arduous testing and climatic conditions. We acknowledge the skilled technical assistance of James Whitham in the control and supervision of the walks. The study was supported by Masterfoods Inc.

**REFERENCES**