The influence of physical activity on BMR

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ABSTRACT

In addition to factors such as fat free mass, hormonal status, genetics and energy balance, previous physical activity has been shown to influence energy turnover during resting (RMR = resting metabolic rate) or basal conditions (BMR = basal metabolic rate). This article presents data on BMR from elite endurance athletes (4 female and 4 male), at least 39 h after their last training session, in comparison with sedentary nonathletic controls matched for sex and fat free mass (FFM). Comparisons with theoretical calculations of BMR were also made. The athletes were shown to have a significantly higher BMR than was expected from calculations based on body mass (16%, \( P < 0.05 \)) or body composition (12%, \( P < 0.05 \)). There were no corresponding differences found in the nonathletic control group. The athletes had a 13% higher (\( P < 0.001 \)) BMR than controls if related to FFM and 16% (\( P = 0.001 \)) if related to both FFM and fat mass (FM). The athletes were also found to have 10% lower R-values (\( P < 0.01 \)) indicating higher fat oxidation. The conformity of these findings with the present literature and the possible mechanisms behind them as well as its influence on theoretical calculations of energy turnover (ET) based on activity factors expressed as multiples of RMR are further discussed.

The major intrinsic determinant of metabolic rate during rest has been shown to be fat free mass (FFM) \( (29) \). Factors such as thyroid hormones, catecholamines \( (17) \), genetics\( (12,37) \), as well as menstrual phase\( (62) \) and menstrual dysfunction\( (32) \) are additional determinants. Energy balance is an extrinsic factor known to influence metabolic rate. Undereating has been shown to lower resting metabolic rate (RMR)\( (38,46,51) \), while overeating increases RMR\( (31) \). Several authors have also addressed the influence of previous physical activity on basal metabolic rate (BMR) and RMR\( (3,6,31,38) \). Most effort in this field has been spent on studies to clarify the short-term effect of physical exercise on metabolic rate. The term excess post-exercise oxygen consumption(EPOC) has been used to describe the phenomenon of elevated oxygen consumption after exercise \( (22) \). Atwater and Benedict\( (2) \) and Benedict and Carpenter \( (8) \), in the early 20th century, were the first to note a prolonged increase in oxygen consumption after
physical exercise. In 1935 Edwards and coworkers (21) reported a mean increase in oxygen consumption of 15% during a 15-h recovery period, in subjects who participated in an American football game. They postulated that as much as 50% of the energy requirement of football playing remained to be accounted for after the game.

We have previously reported (43) data on energy turnover (ET) in world class cross-country skiers, using the doubly labeled water technique. When we compared measured ET with calculated ET from training records and previously published BMR related activity factors (MET) (1), we found large discrepancies in these subjects. To evaluate to what extent a higher BMR may have influenced these calculations, we decided to also measure BMR in the same subjects.

In this article we present data on BMR in world-class endurance athletes, 39 h or more after their last training session. Measured BMR was compared with theoretical calculations of BMR based on body mass (BM), height (H), and age or a combination of FFM and fat mass (FM). An additional comparison was made to the BMR of matched sedentary controls. We also report the effect of increased BMR on theoretical calculations of ET in elite athletes using previously published activity factors (MET) (1) in comparison with measured ET.

METHODS

Subjects

Four female and four male cross-country skiers from top international level and eight matched sedentary controls participated in the study after giving their written consent. The sedentary control subjects were chosen in order to match the athletes for sex and FFM. The study was approved by the ethical committee of the faculty of medicine at Uppsala University. The athletes were the same as those who were observed in a previously published study on total daily energy turnover during a normal training period (43). The descriptive data for the subjects are presented in Table 1.

| TABLE 1. Descriptive characteristics of subjects. |
|----------------|----------------|----------------|----------------|
|               | Females        | Males         | Athletes       | Mean Difference |
|               |                |                | Females        | Males         |
| Age (yr)      | 25 ± 1         | 25 ± 2         | 25 ± 2         | 26 ± 2         | 2 ± 4     |
| Height (cm)   | 171 ± 7        | 168 ± 5        | 166 ± 2        | 180 ± 6        | 6 ± 0.1   |
| Weight (kg)   | 69.1 ± 3.2     | 77.7 ± 9.2     | 54.4 ± 6.1     | 75.1 ± 4.9     | 4.2 ± 0.9* |
| Body fat (%)  | 25 ± 3         | 18 ± 6         | 18 ± 3         | 12 ± 1         | 6 ± 0.1** |
| FM (kg)       | 15 ± 1.6       | 14 ± 6.2       | 9.4 ± 0.3      | 9.6 ± 0.8      | 5.6 ± 0.4*** |
| FM (% of BM)  | 45.0 ± 3.4     | 60.1 ± 6.6     | 46.9 ± 3.1     | 56.3 ± 4.2     | 0.7 ± 2.7  |

Mean = 50 for the groups as well as mean difference for all matched pairs. Significant differences (paired t-tests) between controls and athletes are denoted by: *0.05 > P > 0.01; **0.01 > P > 0.001; *** P < 0.001. FM = fat mass; FFM = fat free mass.

Exercise

The control subjects had not been engaged in physical training for at least 1 yr previous to the measurements. The athletes were training according to their normal schedule (in season). All subjects had been restricted from any excess physical exercise (beyond their normal sedentary activities) for at least 39 h before BMR was assessed at the metabolic unit.

Body Composition

After voiding in the morning, nude body weight was measured. FFM was calculated from body composition, determined by underwater weighing for the controls and by isotope dilution, using deuterium (29), for the athletes. These methods have been shown to agree well with each other (55).

Basal Metabolic Rate

After 8 h of sleep, at our metabolic unit, the subjects were awakened at 6 a.m. and the basal metabolic rate (BMR) was assessed without any further disruption (awake but at complete rest in the fasting state).
A ventilated open hood system was used to measure oxygen consumption and carbon dioxide production (Sensor-Medics 2900Z) over a 30-min period. BMR was automatically calculated from the oxygen and carbon dioxide values, by the equipment, using a modified Weir equation (3.94 \( \dot{VO}_2 \) + 1.00 \( \dot{VCO}_2 \)). The mean value for 15-min of steady state at the end of the 30-min measuring period was used as BMR. Subjects were visually monitored to make sure that they were laying awake but still. The sedentary controls were measured on two different occasions, 2-7 d apart. The mean difference found for the sedentary controls was 0.06 MJ·d\(^{-1}\) (0.9%, NS, CV = 3.9%).

Theoretical values of BMR were calculated using the following equations:

\[
\text{BMR (kJ · d}^{-1}\) = 55 · BW (kg) + 1397.4 · H(m) + 146
\]

(females, WHO/FAO/UNU) (56)

\[
\text{BMR (kJ · d}^{-1}\) = 64.4 · BW (kg) - 113 · H(m) + 3000
\]

(males, WHO/FAO/UNU) (56)

\[
\text{BMR (MJ · d}^{-1}\) = 0.102 · FFM (kg) + 0.024 · FM (kg) + 0.85
\]

(both genders, Westerterp et al.) (53)

Theoretical Calculations of Total Energy Turnover

To compare measured daily ET in the present athletes (obtained with DLW (43)) to values of daily ET calculated as proposed in the literature (based on activity records), 5% was added to the BMR. This was done as the proposed activity factors are based on RMR, which often includes some diet-induced thermogenesis. To estimate ET for various activities, the energy factor (8 MET = moderate effort) most appropriate in relation to the perceived exertion noted by the skiers (3 = moderate, on a scale 1 to 5) was chosen (1). The activity factor (14 MET) for cross-country ski racing (>8.0 mph) was also used for comparison. This is the most appropriate of the factors given for skiing in relation to these subjects' actual training speed. The BMR factor 1.55, proposed by WHO/FAO/UNU(56) for sedentary life, was used to calculate ET during the time when the athletes were not training. To validate these calculations of total ET in the skiers, previously obtained data on total ET assessed by the use of the doubly labeled water technique (43) was used.

Statistics

\(T\)-tests for dependent samples were used to reveal significant differences in subject characteristics as well as in measured BMR (indirect calorimetry) between the skiers and their matched controls. Two-way ANOVA was used to determine whether predicted BMR, calculated from anthropometric data, differed from measured BMR (indirect calorimetry) in the examined subjects and if this was influenced by training. The level of significance was set at \(P \leq 0.05\). Results are expressed as means ± SD in relative as well as absolute terms.

RESULTS
Both methods used to calculate BMR from anthropometric data, age, gender, etc., lead to significant underestimations ($P < 0.05$) when compared with BMR calculated from measured oxygen and carbon dioxide (indirect calorimetry) (all subjects). The difference was found in the athletes. They showed a 16% ± 8% (7.65 ± 1.35 vs 6.58 ± 1.19 MJ·d$^{-1}$, $P < 0.001$) and 12% ± 7% (7.65 ± 1.35 vs 6.74 ± 1.23 MJ·d$^{-1}$, $P < 0.001$) higher BMR than expected from theoretical calculations according to WHO/FAO/UNU (Fig. 1A) and Westerterp et al. (Fig. 1B), respectively. No differences were, however, found between BMR calculated from measured oxygen and carbon dioxide (indirect calorimetry) and according to WHO/FAO/UNU (6.85 ± 1.11 vs 6.57 ± 0.99 MJ·d$^{-1}$, NS) or Westerterp et al. (6.85 ± 1.11 vs 6.72 ± 1.10 MJ·d$^{-1}$, NS) in the control group.
Figure 1-A) Differences between BMR, based on indirect calorimetry and calculated according to WHO/FAO/UNU (1985), plotted against the former values for BMR. Horizontal dotted lines indicate the mean differences for athletes (filled symbols) and controls (open symbols), respectively. Female athletes, •; female controls, ○; male athletes, ▪; male controls, □. B) Differences between BMR, based on indirect calorimetry and calculated according to Westerterp et al., plotted against the former values for BMR. Horizontal dotted lines indicate the mean for athletes (dotted line and filled symbols) and controls (dotted line and open symbols), respectively. Female athletes, •; female controls, ○; male athletes, ▪; male controls, □.

In comparison with the control subjects the athletes had an average of 13%± 12% (0.139 ± 0.014 vs 0.122 ± 0.007 MJ·d⁻¹·kg⁻¹, P < 0.001) higher measured BMR × FFM⁻¹ (Fig. 2). The ratios between BMR assessed by indirect calorimetry and calculated BMR, taking both FFM and FM into account (Westerterp et al.), were found to be on average 16%± 11% (1.128 ± 0.082 vs 0.979 ± 0.034, P < 0.001) higher in the athletes than in the controls. Respiratory quotients (R) were 10% ± 8% (0.80 ± 0.03 vs 0.88 ± 0.05, P< 0.01) lower in the athletes, compared with the controls.

Figure 2-Relationship between BMR, based on indirect calorimetry, and FFM. Significant difference in intercept ( P < 0.05) but not in slopes between the regression lines of athletes (continuous line) and controls (dotted line), respectively. Female athletes, •; female controls, ○; male athletes, ▪; male controls, □.

Total ET, based on calculated BMR according to WHO/FAO/UNU and BMR-related activity factor 8 MET (=skiing, moderate intensity), during a period of normal training was underestimated (validated against the ET obtained by the doubly labeled water method) by 8.4 ± 3.9 MJ·d⁻¹ (P< 0.001). This difference was reduced to 2.9 ± 2.6 MJ·d⁻¹ (P < 0.01) if measured BMR (indirect calorimetry) was used instead of calculated BMR. On the other hand if the factor 14 MET (skiing, racing speed) was used in combination
with calculated BMR the underestimation was 5.4 ± 3.9 MJ·d⁻¹ (P< 0.001), while no difference was found (-1.0 ± 2.7 MJ·d⁻¹; NS) if the measured BMR was used for the calculation of total ET (Fig. 3).

Figure 3-Differences between calculated total ET using BMR assessed from indirect calorimetry or calculated according to WHO/FAO/UNU (1985) in combination with the MET-factors 8 (moderate perceived intensity) and 14 (racing speed, > 8 mph), respectively, and total ET previously assessed by the doubly labeled water (dlw) technique. Significant differences are denoted** 0.01> P > 0.001 and *** P < 0.001.

DISCUSSION

The findings in the present study show a 13% higher mean BMR × FFM⁻¹ in the athletes compared with the control group after at least 39 h of rest. When related to both FFM and FM (when estimated using equation of Westerterp et al. (53)) the difference in BMR was 16%. This agrees with most studies in the literature. However, the duration of the elevation in BMR is longer than usually reported or measured (24).

One reason for the conflicting data when comparing BMR/RMR in different groups may be due to methodological differences. Most authors, for example, express the metabolic rates as ratios with FFM as the denominator. This has been questioned by Ravussin and Bogardus (39) because the intercept in the BMR-FFM relation might result in misleading conclusions. Although fat tissue has a low metabolic rate per mass, a substantially higher FM will result in a metabolic activity that should not be neglected. Relating BMR not only to FFM but also to FM might therefore be more relevant. Matched for FFM, the controls had an average of 60% (14.9 vs 9.3 kg) more fat (FM) than the athletes in the present study. If we express BMR in relation to both FFM and FM (according to Westerterp et al.) we find the difference between the athletes and the sedentary controls to increase from 13% to 16%.

Subject FA2, who has a previous history of anorexia nervosa, might be of special interest. She had a much lower BMR (-16%) than the other female skiers but matched the sedentary controls as well as theoretical calculations. BMR has been shown to be lower in anorectic subjects but it is not clear whether this may have an effect after such a long time of assumed energy balance as in the present case (27,44,50). If the results from subject FA2 and her matched control subject are omitted, the difference in BMR between the remaining members of the groups increases to 16%± 8% if related to FFM (P < 0.005)
or 24% ± 8% if both FFM and FM are considered ($P < 0.001$). It should be noted, however, that at the
time of the study, this subject showed no signs of ongoing eating disorder. She had been weight stable
for over 2 yr and a previous study based on assisted food records and doubly labeled water also showed
a slightly positive energy balance over a 7-d training period at a mean daily energy turnover of 15.1 MJ·d$^{-1}$
(43).

In addition to the energy cost during the actual physical work, exercise may also influence the energy
expenditure during rest in several ways due to transient responses, persistent metabolic adaptations,
behavioral changes, or by affecting energy balance/energy flux. The short-term effect of exercise is
relatively well-examined. The majority of studies support the idea of an elevated metabolic rate due to
previous exercise. However, the intensity and duration of the exercise bout seem to play an important
role. Intensities below 70% of maximal aerobic capacity do not appear to have a prolonged effect on
post-exercise metabolic rate during rest unless the duration is long(38).

The acute effects of exercise should however not be confused with a potential effect of training state on
BMR, as a result of a long history of endurance training. It is not clear whether the training status as such
has any chronic effect on metabolic rate during rest. The majority of cross-sectional studies have shown
approximately 5%-20% higher BMR or RMR in trained subjects compared to sedentary controls when
related to FFM(7,19,26,33,35,36,47,48). A recent study on cross country skiers (14) found a 16% increase in
RMR when measured 18-20 h after exercise. However, two similar studies on highly trained female
endurance athletes did not reach the same conclusion (41,42). Most studies that have shown an elevated
BMR or RMR tend to have examined this within 24 h of the previous exercise, thereby probably
measuring the effect of the last exercise. Herring and collaborators (24) measured RMR after longer
periods of withdrawal from training. They found a significant drop in RMR between 24 and 39 h,
suggesting that the stimulating effect of the last exercise is unlikely to give a significant increase in
BMR/RMR for as long as 39 h. Other studies have however demonstrated a prolonged effect up to 36 h
post exercise(34).

Many highly trained endurance athletes usually have a high energy flux(high energy intake as well as
energy turnover). If the athletic subjects more or less maintain their eating habits this will clearly lead to a
positive energy balance (overeating) on resting days. This might be the case in our as well as in many
other studies examining the effect of physical activity or fitness level on metabolic rate after a period of
rest if energy balance during this period is not controlled. It is worthwhile to note that in two studies by
Schultz et al. (41,42) female endurance athletes did not have an elevated RMR, and were in controlled
energy balance post-exercise. Newly published papers by Bullough et al. (18) and Thompson et al. (45,46)
also suggest that energy flux/balance is crucial for the effect of exercise on RMR, possibly via thyroid
hormone. Unfortunately, energy intake was not measured in the present study. From previous
experience with these subjects it is known that during days with little or no training they generally overeat
substantially(43). However, on travelling days, as was the case in the present study, this was not so obvious (unpublished data).

There are studies that have examined the effect of intervening exercise programs in previously sedentary
subjects. With a few exceptions these studies show an increase in BMR/RMR(9,23,26,34). However, if the
elevated total energy turnover due to the additional physical activity resulted in a negative energy
balance, this was not always the case(11,17,18,54). It is definitely not clear as to when the effect of an
exercise bout ends and when an elevated BMR may be interpreted as a chronic adaptation attributed to
physical fitnessperse.
the athletes and the controls. We know from several registrations of food intake in these skiers that they usually have a lower fat intake (approximately 30% of total energy intake) than the Swedish population in general, and it is therefore unlikely that differences in diets may explain the lower R-value found in the trained group. Further studies are needed to verify whether there is a difference in the amount of TG/FFA cycling between trained and untrained subjects during resting conditions that may partly explain the increase in BMR in the former subjects.

Devlin et al. (20) characterized the substrate and hormonal fluxes in normal subjects, 2-4 h after exercise and found a two-fold increase in the release of 3-carbon gluconeogenetic precursors such as alanine, pyruvate, and lactate from the nonexercised muscles. These precursors may be substrates for Cori and glucose-alanine cycles in the recovering muscles and explain an additional part of the increased metabolic rate found post-exercise.

Several other possibilities (in the present case probably less likely) have been postulated. The resynthesis of glycogen may, after depletion and in the fed state, be a quantitatively relevant process (4). Elevated levels of noradrenaline after exercise have been found after exercise (13, 20, 49) and are important in the early phase of EPOC but return to normal within a few hours (13). Both lactic as well as alactic oxygen debt are sometimes proposed as explanations for the increased energy turnover immediately post-exercise, but may not play a quantitatively important role, especially several hours after the exercise.

In this study we found that BMR in a group of world-class cross-country skiers is substantially elevated at least 39 h after the last exercise bout, compared with a group of sedentary subjects with matching FFM if energy intake is not controlled. It is, however, not clear whether this is due to a persistent adaptation to endurance training (physical fitness), a high energy intake, a positive energy balance, or whether it represents a late phase in a transient state of elevated metabolic turnover in the recovery of the previous exercise.

This paper also demonstrates that by using the BMR, based on indirect calorimetry, in combination with previously published activity factors (MET) related to perceived intensity, the underestimation of ET is somewhat lowered but still substantial in this group of highly trained athletes. These findings are in line with the results from Boulay et al. (14). They found the estimated daily energy turnover to be 30% higher in a group of male cross-country skiers using recorded heart rate and measured oxygen uptake at different submaximal heart rates compared with estimations based on physical activity journals. No difference between these methods was, however, found in a control group of nonathletes. Great caution should therefore be taken when calculations of energy needs based on activity factors are used, especially in endurance-trained subjects where perceived exertion may be strongly misleading. When possible, some objective measure of intensity (such as speed) or an individual reference to characterize the subject (i.e., maximal aerobic metabolic capacity) should be used. Further work is needed to obtain correction factors to compensate for individual variations in ET related to various subjective activity factors. This is very important to practitioners in the field using these factors as a tool in nutritional guidance to athletes.

REFERENCES


ENERGY TURNOVER; ENDURANCE TRAINING; METABOLIC RATE; PHYSICAL ACTIVITY; POST-EXERCISE METABOLISM