Energy needs in sports

Position of the working group sports nutrition of the German Nutrition Society (DGE)

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Abstract

Athletes expend greater amounts of energy as a result of their training. However, these amounts vary during the competition year and are influenced by such factors as the training period and intensity. Measuring energy expenditure is a complex process that is often achieved through indirect calorimetry. A calculation is possible when certain limitations are taken into consideration. Energy expenditure corresponds to energy requirements. Energy requirements should be covered by energy intake adapted to individual needs. Low energy intake can lead to reduced energy availability. Low energy availability not only has a negative impact on the bone metabolism and menstrual cycle – there may also be consequences of a hematological, metabolic, psychological, gastrointestinal, and immunological nature. This has adverse effects on the performance capacity, training adjustment, concentration and coordination, and can lead to an increased risk of injury. Matching energy intake to energy expenditure is an important cornerstone in the diet of athletes and a significant prerequisite for maintaining their health and performance.

Keywords: sports diet, energy requirements, energy availability, energy expenditure during training

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Introduction

Athletes have special dietary needs. In a consensus statement on sports nutrition, the International Olympic Committee (IOC) stated that diet influences performance capacity and advised athletes to apply dietary strategies adapted to individual needs during and after training and competitions to maximize their physical and mental performance [1]. It should be kept in mind that athletes are not a homogeneous group; there are in fact numerous factors that influence energy and nutrient needs (e.g. body weight, size, body composition, training program, duration, intensity). It must also be considered that, depending on the training and competition phase within the annual cycle and even within any given week, athletes plan the intensity and duration of their training sessions in very different ways [2–4].

A young high-performance athlete also has an increased, growth-related need for energy and nutrients [5, 6]. Furthermore, the body weight and body composition of athletes in competitive sports and especially in youth competitive sports can also vary widely within the same type of sport [7, 8]. This becomes particularly clear in track and field, in which athletes in endurance sports weigh 50–60 kg and throwers can weigh up to 130 kg [9].

Energy requirements

While energy intake of humans is limited to their meals and possibly drinks, energy expenditure is a continuous activity designed to maintain numerous processes and functions in our bodies. Daily energy requirements correspond to the energy expenditure over a 24-hour period [10]. Accordingly, appropriate energy intake is a key factor in the human diet. Ideally, the energy intake matches the energy requirements. This is the amount of nutritional energy that guarantees a stable body weight and promotes health and fitness [10]. However, energy requirement is not a fixed quantity and is influenced by numerous factors. These include e.g. body weight, body composition, physical activity, growth, pregnancy, and nursing period. Physical activity is the most variable component in energy requirements [10, 11].

Adult endurance athletes report training programs ranging from 500 to 1,000 hours per year [4] or a running distance of > 150 km per week [2, 4]. In extreme situations such as the *Tour de France* or Race Across America, energy expenditure may be five times as much as when the athletes are at rest [12, 13]. For individual long-distance races, this can result in an energy expenditure of > 10,000 kcal per day [14]. In contrast, there are also phases with low physical activity during a training year, in which daily energy requirements are at a lower level, owing to a potential training period of less than two hours per week. This makes it comparable to that of a person who exercises recreationally [2–4].

Based on the factors that influence the energy expenditure outlined above, the energy needed by most athletes lies between 1,500 kcal and 6,000 kcal per day and during the sports season can be estimated at 2,000 kcal to 5,000 kcal per day for a person weighing 70 kg, for example [3].

> **This variation in individual energy requirements must be considered during nutrition counseling. As a result, nutrition counseling professionals must address the type of sport/discipline and conditional training and competition exertions in order to get an accurate estimate of (current) energy requirements.**

Measurement and estimate of energy requirements

Energy expenditure can be determined through various methods (e.g. direct calorimetry, indirect calorimetry, heart rate) [10]. Indirect calorimetry is often used under lab conditions. In this process, the oxygen intake (VO_2) and carbon dioxide output (VCO_2) are measured via spirometry in liters per minute and calculated according to the Weir formula [15].

Weir formula: Energy (kcal/min) =
$$3.9 \text{ x } VO_2 \text{ (l/min)} + 1.1 \text{ x } VCO_2 \text{ (l/min)}$$

Indirect calorimetry makes it possible to determine the resting energy expenditure, the basal metabolic rate and the total energy expenditure. Additionally, VO_2 and VCO_2 can be recorded with mobile devices during selected physical activities in the field. By using portable spirometry for a soccer training game, it was possible to show an average energy consumption of 1,340 kcal for a period of 90 minutes, but there were great differences in the energy consumed by the studied players (1,050–1,750 kcal) [16]. When measuring energy expenditure with spirometry, it should also be noted that the additional CO_2 formed by the bicarbonate buffer system with increased training intensity limits the accuracy of the values determined through indirect calorimetry for energy expenditure and substrate utilization. This applies particularly to physical exercise above a respiratory quotient (RQ)[1] of 1.0.

Despite these limitations, it is possible to capture energy expenditure during physical activities through spirometric data for guidance. The results from numerous studies to determine the oxygen intake (VO_2) during selected physical activities were summarized in the Compendium of Physical Activities [18–20] and are updated regularly on the Compendium website [21]. The Compendium has established itself as a widely used and accepted source to estimate energy consumption in recent decades [6, 20]. The information in the Compendium is provided as a so-called "metabolic equivalent of task (MET)" (◆ Box).

The MET values describe specific activities, for which activity-related data are then available (◆ Table 1). The MET values of the Compendium are in a range of 0.95 (sleeping) and 23 (running at 22.4 km/h) [20].

Metabolic equivalent of task (MET)

One MET corresponds to resting energy expenditure and is defined as 1 kcal per kg of body weight per hour (kcal/kg body weight/hour). The MET values accordingly stand for a multiplication factor of resting energy expenditure (see examples 1 and 2). This is comparable with information about the Physical Activity Level (PAL). This is defined as the ratio of total energy expenditure to resting energy expenditure, but in contrast to MET, the applicable period is 24 hours. The PAL value thus refers to the additional daily energy consumption used during physical activities relative to the resting energy expenditure [10, 22].

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[1] RQ refers to the quotient of the carbon dioxide volume released per time unit (VCO_2 l/min) to the absorbed oxygen volume (VO_2 l/min). With a high intensity of training, the CO_2 production exceeds the O_2 absorption, so that the RQ rises to values over 1 [17].

Everyday activities	METs	Code
Sleeping	0.95	07030
Sitting quietly, e.g. in front of the TV	1.3	07020
Meeting while sitting	1.5	11585
Office work	1.5	11580
Ironing	1.8	05070
Walking leisurely (< 3.2 km/h)	2.0	11791
Cooking, preparing food	2.0	05050
Shopping at the supermarket	2.3	05060
Housework, cleaning	2.5	05040
Garden work (leisurely)	3.0	08260
Garden work (strenuous)	6.0	08262

Sports activities	METs	Code
Badminton (general)	5.5	15020
Badminton (competitive)	7.0	15030
Basketball (general)	6.0	15050
Basketball (competitive)	8.0	15040
Boxing (with punching bag)	5.5	15110
Boxing (sparring)	7.8	15120
Darts	2.5	15180
Soccer (general)	7.0	15610
Soccer (competitive)	10.0	15605
Golf	4.3	15265
Jogging (6,4 km/h)	6.0	12029
Jogging (8 km/h)	8.3	12030
Jogging (11,2 km/h)	11.0	12070
Jogging (16 km/h)	14.5	12120
Jogging (22,4 km/h)	23.0	12135
Biking (9 km/h)	3.5	01018
Biking (18 km/h)	6.8	01020
Biking (24 km/h)	10.0	01040
Swimming breaststroke (general)	5.3	18255
Swimming breaststroke (intensive)	10.3	18260
Swimming freestyle (general)	5.8	18240
Swimming freestyle (2:10 min/100m)	8.3	18290
Swimming freestyle (intensive)	9.8	18230
Squash (general)	7.3	15652
Tai Chi, Qi Gong	3.0	15670
Tennis (general)	7.3	15675
Table tennis (general)	4.0	15660
Volleyball (general)	4.0	15710
Volleyball (competitive)	6.0	15711

Tab. 1: **Selected everyday activities and sports activities with the corresponding METs and codes**

Based on the knowledge of resting energy expenditure (see formula for the calculation below), it is possible to calculate energy expenditure for different activities (◆ Example 1 and 2).

This approach has established itself for estimating the energy expenditure during physical activity, but it comes with a few limitations that must be considered [6, 20]. For example, the METs only apply for people without a mental or physical disability aged 18–65 years. It should also be considered that persons who are more physically fit reach a higher metabolic rate per unit of time with the same relative intensity of training [23]. The intensity information (e.g. casual, general, strenuous) for the METs may be particularly misleading. Subjectively, a sports activity (e.g. soccer) can be perceived as very strenuous (e.g. owing to poor fitness). However, it is quite possible that a trained player has objectively run more and thus also shows greater energy expenditure while perceiving the activity "only" as moderately strenuous.

Additionally, a key factor in estimating energy expenditure is knowledge of resting energy expenditure. This can be determined with an indirect calorimetry, as described above. This is a complicated process, however, and is only rarely applied as a matter of routine. In general, the resting energy expenditure is thus calculated with available formulas.

However, studies have shown that the calculated values do not always correspond to the measured values [26, 27]. Although the mean values may generally coincide, there may still be a considerable discrepancy between measured and calculated resting energy expenditure in individual cases [26, 27]. Since the fat-free body mass significantly influences the resting energy expenditure and is generally higher in athletes than non-athletes, it makes sense to use a corresponding calculation formula that takes fat-free body mass into ac-

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Note: Table 1 shows selected activities from the Compendium of Physical Activities. A complete and updated overview of the available METs can be found at https://sites.google.com/site/compendiumofphysicalactivities/Activity-Categories. The activities can be found in the Compendium with the codes listed in Table 1.

Example 1: Calculation of energy expenditure during office work

Adult with a body weight of 75 kg
Resting energy expenditure (REE) approx. 1,800 kcal per day or 75 kcal per hour

METs for "office work" *(sitting tasks, light effort [e.g. office work...] Code 11580)* = 1.5

REE per hour x METs = metabolic rate per hour
75 kcal x 1.5 METs = 112.5 kcal per hour of office work

Example 2: Calculation of energy expenditure during soccer

Soccer player weighing 75 kg
Resting energy expenditure (REE) approx. 1,800 kcal per day or 75 kcal per hour

METs for "soccer competitive" *(Code 15605)* = 10

REE per hour x METs = metabolic rate per hour
75 kcal x 10 METs = 750 kcal per hour
Corresponds to an estimated energy expenditure of 750 kcal per hour of soccer or 1,125 kcal for 90 minutes

Conventional formulas to calculate resting energy expenditure (REE) are:

Harris and Benedict (1918) [24]

Men: REE [kcal/day] = 66.5 + 13.8 x weight [kg] + 5.0 x size [cm] – 6.8 x age [years]
Women: REE [kcal/day] = 655 + 9.6 x weight [kg] + 1.8 x size [cm] – 4.7 x age [years]

Cunningham (1980) [25]

REE [kcal/day] = 500 + 22 x LBM (Lean Body Mass = fat-free mass)

Müller (2004) [10]

REE [MJ/day]* = 0.047 x weight [kg] + 1.009 x gender (women = 0, men =1) – 0.01452 x age [years] + 3.21
*Conversion of MJ into kcal by multiplying by 239

count. The Cunningham formula (1980) is often applied in this respect. However, studies that compare the Cunningham formula with measured resting energy expenditure data show inconsistent results [27, 28].

Additionally, resting energy expenditure varies and may not be considered a fixed quantity. In some types of sports (e.g. weight-class sports, ski jumping, endurance sports), there are attempts to reduce body mass during selected periods in a season or to keep it low by means of a chronically low energy intake. This can lower resting energy expenditure during the season. However, this effect seems to be cancelled out at the end of the season with correspondingly higher energy intake [29].

Particularly in competitive sports, it may not be possible to establish a universally valid formula to calculate resting energy expenditure. Reasons for this can be found in the large discrepancies in the area of the anthropometric data, phases of restrictive energy intake with an accompanying decrease in resting energy expenditure [29] as well as in the training phases that generally change, with varying training intensity and volume. Despite these described limitations, the use of formulas to calculate resting energy expenditure when supplementing the MET concept is considered useful for estimating energy requirements [6]. However, it is always worth exercising sound judgment and care when evaluating the calculated result.

Energy availability

In some types of sports or disciplines (e.g. ski jumping, high jump, marathon running), low body weight can provide an advantage in the performance or the regulations may necessitate a certain body weight on the day of the competition. To attain low body weight, athletes tend towards chronically low energy intake or, if possible, an increase in energy expenditure during training [30, 31]. This is often referred to as a negative energy balance as well as low energy availability (EA).

Energy availability is defined as:

Energy availability = energy supply – energy expenditure during training

Example 3: Evaluation of energy availability (EA)

Female athlete with a body weight of 60 kg, 20% body fat, 80% FFM (= 48.0 kg FFM)
Energy intake 2,600 kcal, energy expenditure during training 400 kcal
EA = 2,600 kcal – 400 kcal = 2,200 kcal
2,200 kcal/48 kg FFM = 45.8 kcal/kg FFM

Example 4: Energy availability (EA) of a female athlete with low energy intake and increased energy expenditure during training

Female athlete with a body weight of 60 kg, 20% body fat, 80% FFM (= 48.0 kg FFM)
Energy intake 1,800 kcal, energy expenditure during training 600 kcal
EA = 1,800 kcal – 600 kcal = 1,200 kcal
1,200 kcal/48 kg FFM = 25 kcal/kg FFM

The EA is referred to in kcal per kg of fat-free mass (FFM) (◆ Example 3 and 4).

The concept of energy availability is prevalent especially in sports nutrition and refers less to the traditional energy balance; instead it mainly considers the supplied amount of energy minus the energy used during sports. This results in the amount of energy available to the organism to maintain its basic functions [6, 32]. Studies involving female athletes show that low energy availability (< 30 kcal per kg FFM) leads to a higher risk of signs of fatigue and overtraining, immunodeficiency, menstrual disorders, and stress fractures [32, 33]. Low energy availability is also seen as closely related to the development of the Female Athlete Triad. This is a symptom complex related to cycle disorders, impaired eating behavior, and lower bone density in female athletes [34, 35].

This phenomenon has not yet been systematically studied in men, but comparable results may be assumed [36–38]. Since low energy availability can occur in both genders, it was suggested that the term Female Athlete Triad be replaced with the term Relative Energy Deficiency in Sports (RED-S) [39]. This is also intended to take into account that low energy availability does not limit itself to bone metabolism and cycle disorders, but can also have hematological, metabolic, psychological, gastrointestinal, and immunological consequences. This is associated with negative influences on performance capacity, training adjustment, concentration, coordination, and an increased risk of injury [6]. More in-depth information on this topic can be found in the freely accessible review by Nattiv et al. (2007) [34], De Souza et al. (2014) [35], Mountjoy et al. (2014) [39], Mountjoy et al. (2008) [21] and in a special issue of the International Journal of Sport Nutrition and Exercise Metabolism (Volume 28, Issue 4, July 2018).

Risk groups for low energy availability include athletes who deliberately ensure they have low body weight (e.g. weight reduction phase, permanently low body weight) or are pressured to maintain low body weight. Low energy availability may also affect athletes who e.g. do not eat enough for lack of time and/or underestimate their own energy requirements. It may also be attributable to the fact that hunger is suppressed for sports-related reasons, leading to insufficient energy intake [33]. In phases of weight loss, it is important to ensure that energy availability of 30–45 kcal per kg FFM is guaranteed despite reduced energy intake [33].

> **When applying the concept of energy availability in a consulting practice, it must be borne in mind that information is needed on energy intake, energy expenditure during training as well as data regarding fat-free mass.**

The limitations relating to determining energy expenditure are described above. General challenges in determining energy intake through the various nutrition survey systems are not part of this position paper but described in detail elsewhere [40–42].
Additionally, in nutrition surveys with athletes, it must be kept in mind that a one-time documentation of diets (e.g. once per year) will lead to a flawed evaluation of the nutritional situation, since energy intake can vary greatly owing to the different levels of exertion in training and competitions. The phenomena of underreporting, underrecording or underestimation and overestimation also occur in this group [40–43]. The significant causes named here include changes in eating behavior during the protocol phase, erroneous statements due to social desirability, and documentation errors in terms of the amount and description of the consumed foods [41]. In nutrition surveys, athletes seem to “forget” to record such things as snacks or drinks, which

can result in an erroneous evaluation of their energy intake [41, 43]. Overall, this can lead to a misinterpretation of energy intake in the range of 10–45% [41] and in individual cases to a caloric deficit of > 1,500 kcal per day [27].

Additionally, the body composition must be measured to obtain information on fat-free mass. Different results may be obtained depending on the measuring method [44], however, which, in turn, influences the calculation of energy availability.

> **Despite the limitations described above, it is recommended that more attention be paid to the topic of energy requirements in sports so that warning signals for low energy availability and the associated negative consequences on health and performance can be detected at an early stage.**

Conclusion

Depending on the training and competition phase within the yearly cycle, there can be enormous differences in energy requirements of athletes. Determining energy expenditure precisely is not easy, but can nevertheless be approximated. Energy intake that is adapted to individual needs is a key cornerstone in sports nutrition. In general, it is thus important to ensure adequate energy intake appropriate for the situation in order to meet the training and potentially growth-related needs. Inadequate energy intake can lead to low energy availability with the previously described consequences for health and performance.

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Conflict of Interest
The authors declare no conflict of interest.

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