Energy needs in sports

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

Hans Braun, Anja Carsohn, Mareike Großhauser, Daniel König, Alfonso Lampen, Stephanie Mosler, Andreas Nieß, Helmut Oberritter, Klaus Schäbethal, Alexandra Schek, Peter Stehle, Kiran Virmani, Rainer Ziegenhagen, Helmut Heseker

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

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 expenditure can be determined through various methods (e.g. direct calorimetry, indirect calorimetry, heart rate) [10]. Indirect calorimetry, often used under lab conditions, is the most variable component in energy requirements [10, 11].

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 (VO₂) and carbon dioxide output (VCO₂) are measured via spirometry in liters per minute and calculated according to the Weir formula [15].

**Weir formula:** Energy (kcal/min) = 
\[3.9 \times VO₂ (l/min) + 1.1 \times VCO₂ (l/min)\]

Indirect calorimetry makes it possible to determine the resting energy expenditure, the basal metabolic rate and the total energy expenditure. Additionally, VO₂ and VCO₂ 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 CO₂ 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) 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 (VO₂) 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 (VCO₂ l/min) to the absorbed oxygen volume (VO₂ l/min). With a high intensity of training, the CO₂ production exceeds the O₂ absorption, so that the RQ rises to values over 1 [17].
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 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-

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

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

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

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) 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

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
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).

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 \[41\].

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.

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).
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.

Corresponding author

Klaus Schäbethal
schaebethal@dge.de

Hans Braun
Prof. Dr. Anja Carlsohn
Dr. Mareike Großhauser
Prof. Dr. Daniel König
Prof. Dr. Dr. Alfonso Lampen
Dr. Stephanie Mosler
Prof. Dr. Andreas Nieß
Dr. Helmut Oberritter
Klaus Schäbethal
Dr. Alexandra Schek
Prof. Dr. Peter Stehle
Dr. Kiran Virmani
Dr. Rainer Ziegenhagen
Prof. Dr. Helmut Heseker
1 Institut für Biochemie
Deutsches Forschungszentrum für Leistungssport – momentum; Deutsche Sporthochschule Köln
2 Fakultät Life Sciences/Department Ökotrophologie
Hochschule für Angewandte Wissenschaften Hamburg
3 Olympiastützpunkt Rheinland-Pfalz/Saarland
4 Institut für Sport und Sportwissenschaft
Arbeitsbereich Ernährung
Albert-Ludwigs-Universität Freiburg
5 Abteilung Lebensmittelsicherheit (Abt. 5)
Bundesinstitut für Risikobewertung (BfR)
6 Institut für Gesundheitswissenschaften
Abteilung Ernährung, Konsum und Mode
Pädagogische Hochschule Schwäbisch Gmünd
Olympiastützpunkt Stuttgart
7 Abteilung Sportmedizin
Medizinische Klinik
Universitätsklinikum Tübingen
8 Deutsche Gesellschaft für Ernährung e. V. (DGE)
9 Redaktion Leistungssport (DOSB)
10 Institut für Ernährungs- und Lebensmittelwissenschaften
Ernährungsphysiologie
Rheinische Friedrich-Wilhelms-Universität Bonn
11 Institut für Ernährung, Konsum und Gesundheit
Fakultät für Naturwissenschaften
Universität Paderborn
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