SPORTS NUTRITION IN PARA ATHLETES

DETERMINING ENERGY REQUIREMENTS

– Elizabeth Broad, USA and Claudia Juzwiak, Brazil

Having a reasonable estimate of energy requirement (ER) is important to determine the adequacy of energy intake to cover the demands of sport. This, in turn, prevents the possibility of low energy availability and provides direction for changes in diet and/or training to better support desired physique changes (increased muscle mass, reduced body fat) or improvements in training performance.

One of the main challenges a sport and exercise professional faces when working with para athletes is estimating their energy requirements. Besides the scarce literature in this area, most studies currently available were either conducted on impaired non-athletes, had very small subject numbers or are simply outdated. Therefore, the aim of this paper is to summarise the research available and to provide some practical insight into the factors that should be considered when determining the energy requirements of para athletes.

ENERGY REQUIREMENT

Energy requirement can be defined as "the average dietary energy intake that will compensate for energy expenditure[1]". Energy expended throughout the day or total daily energy expenditure (TDEE), consists of basal energy expenditure (BEE) or resting energy expenditure (REE), thermic effect of feeding (TEF) and energy expended through physical activity (EEEx).

Resting Energy Expenditure (REE)

REE (alternatively known as resting metabolic rate or RMR) represents the energy (kcal/day) required to sustain the metabolic activities of cells and tissues and to maintain the basal cost of living, measured under resting conditions, in a fasting state and a thermoneutral environment and extrapolated over 24 hours. While REE is the main determinant of TDEE in sedentary populations, the contribution varies widely in an athlete population according to training loads. An inaccurate estimation of REE can lead to the over- or under-prediction of energy requirements, potentially leading to positive or negative energy balance, which may affect sporting performance.

The most accurate techniques to assess REE are the doubly labelled water method, and direct and indirect calorimetry. However, these techniques require expensive equipment and specialised personnel, and are not always accessible. The alternative option is the use of predictive equations, derived from calorimetry studies, which allow an estimation of REE. Currently, the available equations are those that were obtained from studies based on the general population. One equation has been developed in a spinal cord injured (SCI) population, however, subjects were a sedentary population of 28 individuals (male and female). Additionally, this equation uses height as a predictive measure, which is difficult to measure in this population[2].

Table 1

Physical impairment	*Characteristics and factors*
SCI	*Measured REE values of individuals with SCI are 14-27% lower than able-bodied individuals* *The level of injury and completeness of injury will affect REE due to:* • *muscle atrophy below the level of injury* • *reduced production of catecholamines (less sympathetic nervous system availability)* *Individuals are more prone to variations in adaptive thermogenesis due to the reduction in thermoregulatory capacity and the influence of medication*
CP	*Higher REE when compared to able-bodied individuals if the individual experiences spams or uncontrolled movements (e.g. dyskinesia, athetosis.* *The lower REE observed in spastic CP can be due to a low energy intake leading to low energy availability.*
LD	*The more extensive and proximal the amputation, the lower the REE*

SCI=spinal cord injury, CP=cerebral palsy, LD=limb deficiency. Source: [10, 11, 12, 13].

Table 1: Characteristics and factors affecting REE according to physical impairment.

The American College of Sport Medicine[3] recommends the use of Harris-Benedict[4] and Cunningham equations for athletes. The Cunningham[5] equation [RMR = 500+22*{kg of free fat mass (FFM)}] gained popularity for use with able-bodied athletes after studies indicated that this equation provided the most accurate REE estimate when compared to indirect calorimetry able measurements of female and male endurance athletes. A similar study[6] was conducted on para athletes with cerebral palsy, limb deficiency and visual impairment, in which measured REE (assessed by indirect calorimetry) was compared with values predicted by several equations (Harris-Benedict, Cunningham, Food and Agriculture Organization/World Health Organization [FAO/WHO], Dietary Reference Intake [DRI], Owen and Mifflin-St-Jeor). Owen's equations[7,8] reflected the smallest variation from measured REE values in athletes with limb deficiency and with cerebral palsy, overestimating REE by 104 and 125 kcal/day (within 10% of measured values), respectively, while the equation proposed by Mifflin-St Jeor[9] had the best REE estimate performance for athletes with visual impairment, overestimating by 146kcal/day.

In para athletes, some additional challenges should be considered when estimating energy requirements. Table 1 summarises some of these aspects in the most representative physical impairments.

The use of predictive equations in sedentary individuals with SCI have been reported to overestimate REE by 5 to 32%, which is likely due to a reduction in lean body mass relative to height, weight and age (the key components on which many prediction equations are based). Pelly et al[14] assessed six male SCI athletes and showed that while absolute measured REE was lower compared to matched active able-bodied controls, when adjusted for fat free mass (FFM) the differences were reduced such that the REE/kg FFM was the same between groups. Additionally, the Cunningham equation (which uses FFM) best estimated REE in the SCI group compared to Owen, Harris-Benedict, Schofield and Mifflin-St Jeor equations. Despite the Cunningham equation providing the best estimate, there was an average 64 kcal/day (~4%) difference between measured and estimated REE.

Overall, it appears that if using predictive equations, the best option is to use one that requires an estimate of FFM, such as Cunningham or Owen, provided FFM can be accurately and validly measured.

Thermic Effect of Feeding

Following the ingestion of food, energy expenditure increases in humans in a manner that varies with the amount and composition of food consumed. This is described as the thermic effect of feeding and accounts for approximately 5 to 15% of total daily energy expenditure. It is the most difficult component of TDEE to reproduce in studies as it can be affected by several factors[11]. Buchholtz & Pencharz[11] completed three studies of individuals with SCI and reported no difference from the TEF of able-bodied individuals when values were adjusted for energy consumed. Monroe et al[15], in contrast, found significantly lower absolute and relative TEF in 10 sedentary SCI males (12.9% of energy intake) compared to able-bodied controls (15.9% of energy intake). No data on individuals (or athletes) with other impairments are available.

Exercise Energy Expenditure

The EEEx includes the expenditure with spontaneous physical activity, non-exercise activity thermogenesis and planned exercise expenditure. It can be estimated by means of devices (calorimeter, accelerometers) or from diaries of the activities performed, which can be later converted using values available in calories (kcal) or in metabolic units (METs)[3]. It is worth remembering that MET tables were also established from studies with able-bodied athletes, with some exceptions. Conger and Basset[16] published values for wheelchair physical activities after a systematic review of studies, while Collins et al[17] evaluated adults with SCI performing recreational and daily life activities using a telemetry system. These authors suggest a lower value (2.7 mL/kg/min) as equivalent to 1 MET for non-elite athlete wheelchair users compared to 3.5 mL/kg/min used in healthy adult athletes. In practice, these values tend to overestimate energy expenditure in athletes most likely due to greater efficiency of movement. Numerous issues arise in the para athlete population in estimating true EEEx:

- Portable devices, such as BodyMedia (Sensewear)™, may not be valid in this population, overestimating energy expenditure of movement (e.g. manual wheelchair users[18]).
- The physiological profiles of many para sports have not been described in the literature (e.g. goalball, sitting volleyball) and there is no 'equivalent' able-bodied sport to compare with.
- Wearable devices, such as heart rate monitors, FitBitTM and Apple WatchTM, have internal programming software that is based on an able-bodied population whose validity is uncertain in many para athlete populations (e.g. short stature, unilateral cerebral palsy, other neurological disorders).

Additional considerations for determining EEEx in athletes with a physical impairment are noted in Table 2.

Additionally, Table 3 summarises results from studies which have measured REE and/or EEEx in para athletes.

TABLE 2

Physical impairment	*Characteristics and factors*
SCI	*EEEx of athletes with SCI ranges from 25 to 75% compared to able-bodied athletes in similar activities; this reduction is associated with:* • *level of injury (lower expenditure among tetraplegic athletes)* • *type of injury (complete or incomplete)* • *type of exercise (lower expenditure in more static sports, such as fencing).* • *level of training (higher EEEx for elite athletes than recreational or lower level athletes in the same activity)* • *reduced production of catecholamines (less sympathetic nervous system availability)* *EEEx of SCI athletes is reduced when compared to able-bodied individuals practicing sports in wheelchairs*
CP	*EEEX is increased when gait imbalance is present, and ambulation status affects TDEE.* *Athetosis may reduce TDEE due to less spontaneous movement throughout the day.*
LD	*EEEx is increased due to asymmetry in movement and/or gait alteration due to use of prostheses or crutches.* *Consideration should be given to the type of prosthesis since stiffness can influence metabolic cost of running.* *The more proximal the amputation, the higher the EEEx.* *Ambulation EE at any speed and any amputation level is higher in dysvascular amputation compared to traumatic amputation.*

Sources: [12, 13, 15, 19, 20, 21].

Table 2: Characteristics and factors affecting EEEx in according to physical impairment.

ENERGY AVAILABILITY

Energy Availability (EA) represents the amount of energy remaining for normal physiological processes, after the energy expended during exercise is considered. Energy availability is calculated as [Energy consumed (kcal) - Energy spent in the exercise (kcal)] / kg FFM. A value of 45 kcal/ kg FFM is considered adequate for athletes and low energy availability (LEA) is defined when EA is ≤30 kcal/ kg FFM in healthy able-bodied individuals[26].

LEA has been suggested as the driving factor of both the Female Athlete Triad (FAT), also involving menstrual status and bone health and Relative Energy Deficiency in Sport (RED-S)[26], a cluster of symptoms of several body systems including increased risk of nutrient deficiency, chronic fatigue, increased risk of infectious diseases and decreased performance. Although there is a higher risk of LEA in athletes who control weight and body composition, it can also happen unintentionally. Like in all athlete populations, LEA may potentially occur due to a lack of understanding regarding the nutritional needs for performance and optimal training capacity, and consequent failure to adjust intake to expenditure.

Some para athletes may intentionally restrict their energy intake to control body mass fearing that excessive weight may alter the fit of prosthetics, sports wheelchairs or reduce functional mobility. Additionally, some para athletes may have difficulty chewing and swallowing, or present with substantial food aversions. Unfortunately, there is a lack of data on the prevalence of LEA in para athletes, as well as on the propensity for FAT and RED-S[27]. Assessing EA in para athletes can be difficult both because of the lack of information available on EEEx, as well as difficulty in accurately assessing FFM. A greater understanding of the incidence of LEA in para athletes is important due to the higher inherent risk of low bone density in many of these athletes associated with their impairment (e.g. SCI, amputees), which may be exacerbated by LEA and because sports-related illness and injury may have heightened functional consequences compared to their able-bodied peers.

BODY COMPOSITION AND ENERGY ESTIMATE

As outlined above, equations used to estimate REE require some component of body composition. In the case of para athletes, even the most basic measures such as height and body mass can be challenging to obtain depending on the extent of the impairment. Furthermore, while there are

TABLE 3

Para athlete population	REE (kcal/d)	Athletes	EEEx (kcal/min)	Reference	Notes
SCI - Tetraplegia and paraplegia		*n=12, male*	*5.2*	*Lakomy*[22]	*5 km time trial on treadmill. EEEx estimated from* VO_2.
SCI - Paraplegia		*n=4*	*8.6*	*Price*[12]	*WB*
SCI - Paraplegia		*n=6, male*	*5.0*	*Roy et al.*[23]	*WT. EEEx estimated from* VO_2.
SCI - Paraplegia		*n=4*	*2.6-6.5*	*Price*[12]	*WB*
SCI - Tetraplegia, paraplegia & leg amp	*1521*	*n=25, male & female*	*6.2-8.1#*	*Abel et al. 2003*[24]	*WC racers & handbikers*
SCI - Tetraplegia (WR) and paraplegia (WB, WT)	*1504-1603*	*n=14, all males*	*4.1-6.2*	*Abel et al. 2008*[25]	*WT, 10 WB, 12 WR*
SCI – Tetraplegia (incomplete)	*1686a*	*n=14a and 5b males*	*7b*	*Broad et al.**	*WR*
SCI - Paraplegia	*1532*	*n=6 males*		*Pelly et al.*[14]	
Cerebral Palsy	*1334*	*n=8, 3 males*		*Juzwiak et al.*[6]	*T&F*
Limb deficiency	*1437*	*n=8, 7 males*			*T&F*
Visually impaired	*1423*	*n=11, 7 males*			*T&F*

*WT=wheelchair tennis; WB=wheelchair basketball, WR=wheelchair rugby; T&F=track and field #2 different exercise intensities.*Unpublished data.*

Table 2: Reported REE and EEEx of para athletes measured by indirect calorimetry.

numerous methods for assessing the body composition of athletes, the individual characteristics and the specificity of each para athlete's impairment may have implications for the choice of method and the interpretation of data. An understanding of the underlying assumptions built into any tool used to assess body composition is essential to determine its validity for para athletes. Table 4 outlines the most common methods available to practitioners and their limitations in a para athlete population.

Surface anthropometry (e.g. skinfolds, girths) can be applied in equations to estimate body composition; however, there are no equations currently validated for the para athletic population. Mojtahedi et al[30] found no consistent agreement in % body fat estimates determined by Bioelectric Impedance Analysis (BIA), Dual-Energy X-Ray Absorptiometry (DXA) and skinfold equations in an SCI athlete population. Willems et al[31] and Sutton et al[32] both showed that skinfold prediction equations developed in able-bodied populations predominantly underestimated body fat percentage (%BF) by 2 to 14% in wheelchair athletes of varying impairments in comparison to DXA. Lemos et al[33], in contrast, found no difference in %BF determined by Air Displacement Plethysmography (ADP) and skinfolds (%BF calculated using Jackson and Pollock equation) in 70 Paralympic athletes including a wide range of impairments and sports. However, the skinfold equation was developed in an able-bodied population and ADP may not provide a valid estimate of FFM across the full para athlete population. Goosey-Tolfrey et al[29] proposed regression equations to estimate FM for wheelchair games players (22 out of 30 of whom were SCI) however these equations used skinfold sites in areas with muscle atrophy (the validity of which is undetermined), involved a wide range of impairments and used DXA as the 'gold standard' tool, which has not yet been validated for body composition in individuals with substantial muscle atrophy. The following equation, including only three upper body skinfold sites (biceps, triceps, subscapular), was shown to yield good results but has not yet been cross-validated: $\%\text{Body fat} = -5.04 + 1.46 \cdot \Sigma SF3 - 0.01 \cdot \Sigma SF3^2$. Even if the physical impairment is minimal (such as visual impairment, intellectual impairment, minimal amputee, mild cerebral palsy), the skinfold equations

Table 4

	Challenges and limitations
Body mass	*For some para athletes it will be necessary to adopt special strategies or equipment to assess BM:* • *sitting cross-legged on the platform of a traditional scale, which should be broad* • *using a seated or wheelchair scale* • *the athlete is weighed being held by another person (previously weighed) and BM is estimated by difference* • *using equations to predict BM, such as equations that use knee height*
Height	*In some athletes with SCI, height can be difficult to assess due to contractures.* *For double leg amputees, pre-injury height may be acceptable if the injury occurred after peak growth was achieved.* *In some situations, the recumbent stature or arm-span can be used as a proxy measure.* *Use of equations that use other anthropometric variables such as knee height may be relevant.*
Body composition	*DXA:* *Not indicated for individuals with spasms (e.g. SCI, multiple sclerosis, CP) since any movement will affect the accuracy of the scan.* *Uncertain accuracy in individuals of short stature and those with muscle atrophy since the tool can only differentiate between two substantially different tissue densities.* *Athletes must be scanned in both a fasted and hydrated state for more accurate body composition assessment.* *Challenges may occur in correct positioning of athlete when contractures are present. Many scanners cannot accommodate very broad or tall individuals hence multiple scans required.* *Metal fixtures (e.g. surgical pins and rods) may alter scan accuracy.*
	BIA: *Not indicated in individuals with SCI (due to change in total body water content and intra- and extracellular water ratios) or amputations (missing unilateral or lower limbs will impact on whole body resistance measurement). The presence of edema may also invalidate results.* *Multi-channel and multi-frequency BIS preferred over BIA.* *May underestimate FM and overestimate FFM in athletes with SCI relative to DXA.*
	ADP: *Overall, presents some drawbacks:* • *difficult to maintain some athletes in a sitting position (e.g. tetraplegia);* • *assumptions of the method are based on the able-bodied and is incompatible with amputation;* • *assumptions of the method is based on consistency of tissue density throughout the body and is incompatible with significant muscle atrophy (e.g. underestimate FM and overestimate FFM in athletes with SCI relative to DXA);* • *difficult to measure residual lung volume of athletes with SCI above T6 due to neural innervation to respiratory muscles.*

DXA=dual energy x-ray absorptiometry; BIA=bioelectrical impedance analysis; BIS=bioelectrical impedance spectroscopy; ADP=air-displacement plethysmography; FM=fat mass; FFM=Fat free mass. Source: Slater[28]; Goosey-Tolfrey et al[29].

Table 4: Anthropometric and body composition assessment of para athletes: challenges and limitations

> **Care should be taken in prescribing energy intakes or body fat levels without full understanding of impairment types, sport type and the athlete's own dietary intake and limitations**

used should be those validated in an athlete population of a similar nature. Validation of DXA and other models to determine FFM in athletes with a range of impairments is necessary.

CONCLUSION

In conclusion, the estimation of TDEE in para athletes requires numerous considerations according to the type of impairment. Prediction equations used to estimate REE should be based on FFM wherever possible, provided an appropriate means of measuring FFM is available. Care should be taken in prescribing energy intakes or body fat levels without full understanding of impairment types, sport type and the athlete's own dietary intake and limitations.

RECOMMENDATIONS

- To estimate RRE, if an accurate method (e.g. indirect calorimetry) is not available, the provider should use Owen or Cunningham's equations if it is possible to get an accurate estimate of FFM; otherwise the Harris-Benedict equation is the better option. If possible, use both forms of estimate (even if FFM may not be accurate) to determine a 'most likely range' of REE.
- It is important to follow-up the athlete's training periodisation, body mass and composition changes to adjust energy intake accordingly.
- If DXA is not available, the provider should monitor body fat changes over time using skinfold and girth measurements taken from several reproducible sites and leaving the measurements in mm or cm.
- Available MET data for able-bodied athletes are likely suitable to estimate EEEx for athletes with visual and intellectual impairment, as well as minimally impaired athletes. EEEx remains a challenge for other impairments – the ideal solution is to obtain accurate measurements using indirect calorimetry or activity monitors. Activity logs help the monitoring of training load and intensity and allow use of MET equivalents to estimate EEEx, which have been modified for athletes with SCI.
- Future research should aim to understand the energy requirements of athletes in various sport settings.

References available at
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Elizabeth Broad Ph.D., B.Sc., Dip.Nutr.Diet., M.App.Sc.

Senior Sports Dietitian

United States Olympic Committee, US Paralympics

Chula Vista, USA

Claudia Juzwiak, Ph.D., M.Sc., R.D.

Professor

Universidade Federal de São Paulo

Santos, Brazil

Contact: elizabeth.broad@usoc.org