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ENERGY EXPENDITURE IN A SYME'S AMPUTEE TRIATHLETE

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Beezhold EJ, et. al. Energy expenditure prediction equations developed for able-bodied populations may be inaccurate for para-athletes, a population characterized by different types of impairments. Sufficient data do not exist currently to generate or validate energy expenditure predictive equations for para-athletes to establish dietary recommendations to cover the demands of sport. The purpose of this observational study was to assess energy expenditure and substrate usage from a trained para-athlete at rest and while performing the athlete's specific mode of exercise. One para-athlete recruited from the Challenged Athletes Foundation (female; age 32) participated in the study. The participant was a left leg Syme's amputee triathlete. Resting metabolic rate was measured for the triathlete. Energy expenditure was also measured at moderate (64-76% of age-predicted HRmax) and vigorous intensity exercise (77-95% of age-predicted HRmax) on a stationary cycle ergometer on a separate day. The triathlete's energy expenditure during exercise was higher than that predicted by the metabolic equivalent of task (MET) matched by exercise type at a moderate (measured: 7.0 kcal/min, predicted: 5.0 kcal/min) and vigorous intensity (measured: 9.3 kcal/min, predicted: 7.0 kcal/min). The Revised Harris-Benedict and the Mifflin-St Jeor equations underestimated resting metabolic rate in the triathlete (measured: 2,194 kcal/day, predicted: 1,348 ± 39 kcal/day). This study indicates that equations developed for able-bodied populations underestimate energy expenditure in a Syme's amputee when compared to the measured energy expenditure values assessed by indirect calorimetry at rest and during a workout on both a stationary cycle ergometer and while running on the track.

Key Words: para-athlete, able-bodied, energy expenditure, resting metabolic rate

INTRODUCTION

Energy expenditure (EE) describes the rate and quantity of substrate utilization in the body for energy (Haugen et al., 2007; Levine, 2005). Para-athletes are a population characterized by different types of impairments. Depending on the type and severity, the disability can result in a change in EE (either increased or decreased) when compared to able-bodied (AB) athletes (Gjovaag et al., 2017; Schmalz et al., 2002; Ward & Merers, 1995). Standard EE prediction equations that were developed for AB populations are inaccurate for para-athletes (Czerniecki et al., 2017; Farkas et al., 2019). Decreased muscle power, a limb deficiency or loss, or leg strength difference are examples of impairments that influence the rate and quantity of substrate utilization (Goosey-Tolfrey et al., 2014). Thereby, it excludes this population from the accurate usage of standard EE prediction equations developed for AB athletes (Farkas et al., 2019; Price, 2010).

EE in the clinical and field setting is well understood for AB athletes (Levine, 2005; Hall et al., 2004). However, data on EE in physically impaired athletes is sparse (Goosey-Tolfrey & Leicht, 2013). This is because there are several limitations when working with a population characterized by a wide variety of types and degrees of impairment (Goosey-Tolfrey et al., 2014). For example, not all protocols designed for an AB population are transferable to physically impaired athletes and some testing equipment cannot accommodate prosthesis or wheelchairs (Goosey-Tolfrey et al., 2016).

Opportunities are growing for physically impaired individuals to participate in exercise and sport (Goosey-Tolfrey et al., 2014). Consequently, efforts are being made to better understand EE at rest and during exercise to enhance training and performance through nutrition and body-weight regulation in the expanding para-athlete population (Edwards et al., 2018). It is valuable to have an estimate of energy requirement to decide the sufficiency of energy intake for sport demands (Goosey-Tolfrey et al., 2016). This can help prevent the likelihood of low energy availability and offers direction in prescribing diet and training to support changes in physique and performance (Blauwet et al., 2017; Goosey-Tolfrey et al., 2014). While there are predictive equations for AB people to estimate energy expenditure, rate of EE during exercise is less studied for para-athletes (Czerniecki et al., 2017). The majority of research looking at individuals specifically with amputation takes place in a clinical setting with non-athletes (Ward & Merers, 1995). Such studies lack ecological validity, an important factor in the practicality of data utilization (Czerniecki et al., 2017).

Athletes with a lower extremity amputation tend to have a higher respiratory exchange ratio (RER), rating of perceived exertion (RPE), oxygen uptake (VO_2), and heart rate (HR) compared to AB athletes at a given submaximal intensity (Gjovaag et al., 2017). The higher energy cost is likely because movement with prosthetics can be inefficient (Goosey-Tolfrey et al., 2014). The location of the amputation also can determine EE because greater tissue loss results in higher levels of energy expended during movement, but lower RMR levels in comparison to an AB individual (Schmalz et al., 2002).

Despite emerging efforts in understanding EE characteristics in athletes with amputation, currently there are insufficient data to generate or validate EE predictive equations for these athletes in order to establish dietary recommendations for appropriate energy intake or sport performance enhancement (Blauwet et al., 2017; Joaguim et al., 2018). The wide variety of impairment types precludes this possibility at present because most studies available involve small subject numbers and do not adequately account for the diverse range of degrees and types of impairments that exist in para-athletes (Goosey-Tolfrey at al.,2013; Price, 2010). However, individual EE data is important for each para-athlete in order for each athlete to understand his or her energy needs during training for optimal fueling and weight management (Gjovaag et al., 2017). Over time, as more para-athletes' EE is documented, it may become possible to develop population-specific EE prediction equations.

Therefore, the purpose of this observational study was to assess EE and substrate usage from a trained para-athlete at rest and during a training session. This information can help dietitians to estimate appropriate energy intake of a Syme's amputee to cover energy costs of the sport. This can provide direction for changes in diet and training to regulate body composition and enhance training and performance. This study also serves as a foundation upon which future research may build. Data from individuals should be matched by type and degree of impairment and mode of exercise to assist in the generation of population-specific EE prediction equations.

METHODS

Participants

Criteria for inclusion were: reporting "no" to all questions on the Physical Activity Readiness Questionnaire (PAR-Q), being at least 18 years of age, an athlete with a physical disability, and currently training for a competitive event or race at a recreational or elite level. The study was approved by an Institutional Review Board and athletes provided written informed consent. One healthy participant was recruited from Challenged Athletes Foundation (Table 1): a recreational triathlete with a left leg Syme's amputation (removal of the foot at the ankle joint). The triathlete was training for a marathon 8 months from the testing date, building mileage through an average of 6 hours of self-reported training per week, excluding resistance training. She had no history of smoking and reported no usage of medications affecting HR during rest and exercise.

Procedures

The triathlete was asked to participate in three different testing days. For each visit, the triathlete was instructed to refrain from alcohol and vigorous exercise 24 hours prior to testing and from caffeine the day of testing. The tests took place one week apart in the exercise science laboratory and on the track of a local university.

Table 1

Athlete Demographics and Energy Expenditure at Rest

Description	Athlete
Impairment type	Syme's amputation (L)
Sport	triathlon
Sex	female
Age (yr)	32
Height (cm)	160
Weight (kg), excluding prostheses	63
Current training (excluding resistance training) (hours/week)	6
Measured resting metabolic rate (kcal/day)	2,194
Resting VO_2 ml/kg/min	5.0
RER	0.80
Kcal/min	1.5
Kcal/kg/min	0.02
% of energy used from fats at rest	67
% of energy used from carbohydrates at rest	33
Resting HR	43 bpm

Note: Metabolic values are averages taken from the last 5-minutes of the resting metabolic test.

On visit one, the triathlete was instructed to fast for at least 8 hours prior. Sex, age, height, weight, and impairment history for the participant were documented. Since the participant was able to assume a standing position, a Seca 206 wall-mounted stadiometer (Seca, Birmingham, United Kingdom) was used to measure height. A Cosmed integrated digital scale (Cosmed, Concord, CA, USA) was used to measure weight, subtracting prosthetic weight from total body mass. The triathlete's everyday prosthetic used for cycling was a Seattle Kinetic Light (0.50 kg) and her running prosthetic was an Ossur Cheetah foot (0.51 kg). The participant was then fitted with the Cosmed K4b2 portable breath-by-breath gas exchange analyzer. The K4b2 was calibrated using manufacturer guidelines before each test. A Polar Unisex Adult Heart Rate Sensor and Pro Chest Strap (Polar, NY, USA) recorded heart rate (HR). Time was tracked using a digital Pro Survivor Stopwatch (Accusplit, Livermore, CA, USA). RMR testing took 45 minutes while the athlete rested in a supine position. The first 20-30 minutes allowed the subject to reach a steady-state while resting comfortably. Gas exchange and ventilatory data were collected in a breath-by-breath fashion and then 30-second averages were used for analysis. Steady-state oxygen uptake was defined as 10 minutes during which VO_2 and ventilation did not vary by >10%. The last five minutes of those 10 minutes of steady state were used for RMR assessment. The following two equations commonly used to predict RMR in an AB population (Frankenfield et al., 2005; Mifflin et al., 1990) were used to predict the RMR of the triathlete and to compare with their directly measured RMR:

Revised Harris-Benedict equation: 447.6 + [9.25 x weight (kg)] + [3.10 x height (cm)] – [4.33 x age (y)]

Mifflin-St Jeor formula: [10 x weight (kg)] + [6.25 x height (cm)] – [5 x age (y)] – 161

On visit two, the triathlete was asked to prepare nutritionally and warm up for a workout as normal to mimic a regular practice. The test was conducted using a stationary cycle ergometer (Monark L7, Varberg, Sweden) to match the triathlete's primary mode of exercise. Once fitted with the K4b2, the triathlete performed in a HR and RPE range (Borg, 1982) according to the American College of Sports Medicine (ACSM) (Garber et al.,

2011) at a moderate (64-76% of HRmax and RPE score between 12-13) and vigorous intensity (77-95% of HRmax and RPE score between 14-17) using age-predicted HRmax (220 – age = HRmax). The exercise test took approximately 45 minutes. EE data were continuously collected for five minutes at rest, during a 1-minute self-paced warm-up, during 15 minutes of moderate intensity exercise, during 15 minutes of vigorous intensity exercise, and during a 5-minute cool-down at a self-selected pace. RPE was recorded every minute, and HR levels were closely monitored during exercise to keep the triathlete's HR within the intensity zones by manipulating bike resistance and encouraging the triathlete to pedal at a consistent rate. Data were used from the last two minutes of each stage after steady-state was reached to calculate EE at the given exercise intensity. RER and caloric expenditure values (kcal/min) were calculated using the following standard metabolic conversion equations used in indirect calorimetry:

RER = Average VCO_2/VO_2, EE = VO2 x caloric equivalent

On visit three, the triathlete was again asked to prepare nutritionally and to warm up for a workout as normal to mimic a regular practice. While wearing the K4b2 on the track, the triathlete ran a mile warm-up, 2x800 m and 1x400 m with a 4-minute recovery between repetitions at a tempo pace, described as "comfortably hard" (Daniels, 2013). The triathlete helped decide the workout to mirror an abbreviated version of her training. EE data was the average of the last minute of each 800 m run and the last 30 seconds of the 400 m run.

Data from both exercise tests were then compared to the metabolic equivalent of task (MET) adopted by ACSM to express the rate of energy expended for a given activity (Ainsworth et al., 2011). Closely matched exercise descriptions with a corresponding MET value were selected from the 2011 Compendium of Physical Activities. Kilocalorie (kcal) values were calculated from METs using the following equations (Ainsworth et al., 2011):

Kcal/hour = MET x weight in kilograms x duration in hours

Kcal/kg/min = kcal/hour ÷ weight in kilograms ÷ 60 minutes

Statistical Analysis

Descriptive statistics are presented for EE, VO_2, and RER at rest and during exercise for the athlete. As this was a case study (N=1), we are reporting the descriptive statistics and visually comparing measured energy expenditure to that estimated by predictive equations.

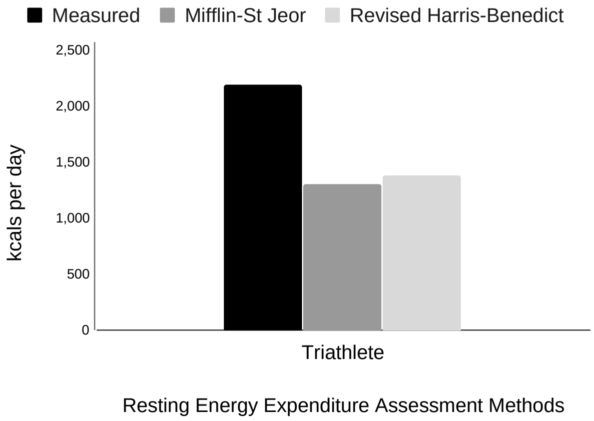
RESULTS

Group Characteristics

The triathlete showed a higher measured RMR (2,194 kcal/day) compared to that predicted by the Revised Harris-Benedict equation (1,387 kcal/day) or the Mifflin-St Jeor formula (1,309 kcal/day) (see Figure 1). The triathlete primarily utilized fat (67%) as a substrate for energy in comparison to carbohydrates (33%) during rest.

Figure 1

A Comparison of Measured and Predicted Resting Energy Expenditure



Energy Expenditure Tests

Heart rate, RPE, rate of EE, and carbohydrate usage increased as intensity increased (see Table 2). The athlete expended higher amounts of energy than the MET equation predicted at a moderate (7.0 kcal/min vs. 5.0 kcal/min, respectively) and vigorous intensity (9.3 kcal/min vs. 7.1 kcal/min, respectively). The METs selected and compared to the exercise test were described as 51-89 watts (W) on a stationary bike at a light-to-moderate effort (4.8 METs) and 90-100 W at a moderate-to-vigorous effort (6.8 METs) (Ainsworth et al. 2011).

Table 2

Measured Cardiorespiratory Responses and an Estimate of Energy Expenditure using Metabolic Equivalents (METs) of a Cycling Workout in a Triathlete with a Syme's Amputation

Variable	Moderate Intensity (64-76% of predicted HRmax)	Vigorous Intensity (77-95% of predicted HRmax)
VO2 ml/kg/min	23.0	30.1
RER	0.8	0.9
Kcal/hour	419	558
Kcal/min	7.0	9.3
Kcal/kg/min	0.1	0.2
% of energy used from fats	56	35
% of energy used from carbohydrates	44	65
HR, beats per minute (bpm)	108	153
Pace: watts (W), rotations per minute (RPM)	45W, 88 RPM	91W, 87 RPM
Rating of perceived exertion (RPE)	12	16
METs kcal/hour	302	428
METs kcal/min	5.0	7.1
METs kcal/kg/min	0.1	0.1

Note. Metabolic values are averages taken from the last two-minutes of each stage.

In-Field Assessment

The triathlete ran an untimed, self-selected pace for a warm-up mile, 2x800 m at 7:28 and 7:06 min/mile pace, and a 400 m at 6:04 min/mile pace with a 4-minute recovery between (see Table 3). The triathlete expended more energy during the 2x800 m compared to that predicted by the MET equation (13.4 kcal/min average vs. 12.7 kcal/min average, respectively), but less energy during the 400 m compared to that predicted by the MET equation (13.7 kcal/min vs. 15.2 kcal/min, respectively). The METs selected and compared to the field-test paces were described as running at 8 mph or 7.5 min/mile (11.8 METs), running at 8.6 mph or 7 min/mile (12.3 METs), and running at 10 mph or 6 min/mile (14.5 METs) (Ainsworth et al. 2011).

DISCUSSION

For the triathlete with a Syme's amputation, substrate utilization occurred similar to an AB athlete, increasing carbohydrate reliance and caloric expenditure with increased intensity (Bergman & Brooks, 1999; Hawley & Leckey, 2015). The triathlete ate a snack before both tests to prepare for the workout, leading to the assumption that the carbohydrates in the snack were used for fuel and suppressed lipolysis, contributing to the increase in carbohydrate reliance (Hawley & Leckey, 2015). MET values under-estimated EE for the triathlete in both cycling and running, with the exception of the 400 m run, which over-estimated EE by 1.5 kcal/min. Measured EE during cycling at a moderate intensity (7.0 kcal/min) was also higher than EE (4.52 ± 0.55 kcal/min) reported in a study looking at cycling efficiency with a sample of 96 healthy young adults (18-40 yr.) cycling at 50W (Gaesser et al., 2018). This is consistent with studies that show athletes with amputation have higher energy costs during exercise at a given submaximal intensity (Gjovaag et al., 2017, Schmalz et al., 2002).

A lower extremity amputation is characterized by the loss of the ankle joint, the muscles that control the joint structure, and the sensory input of the musculature, changing the biomechanics for the cyclist when compared to an AB cyclist (Childers, 2009). Cycling with one intact limb and one prosthetic limb leads to asymmetric work (torque) production (Childers, 2011), which could account for a higher EE than an AB cyclist at a given intensity. Future research needs to assess how asymmetric torque in amputees affects EE during cycling.

Amputees also have higher energy costs during walking and running when compared to an AB person because the use of a prosthetic results in lower energy efficiency (Gjovaag et al., 2018; Czerniecki et al., 2017). Schmalz et al. (2002) found that the style of prosthesis can affect the EE cost of an amputee.

Table 3

Measured Cardiorespiratory Responses and an Estimate of Energy Expenditure using Metabolic Equivalents (METs) of a Track Workout in a Triathlete with a Syme's Amputation

Measurement	Warm-up	1st 800 m	2nd 800 m	400 m
Pace (min/mile)	untimed	7:28	7:06	6:04
Average HR, beats per minute (bpm)	137	161	170	175
Exercise domain	Moderate	Vigorous	Vigorous	Vigorous
VO2 ml/kg/min	34.0	41.6	42.9	43.1
RER	0.9	1.0	1.2	1.2
Kcal/hour	635	795	818	821
Kcal/min	10.6	13.2	13.6	13.7
Kcal/kg/min	0.2	0.2	0.2	0.2
% of energy used from fat	31	0.0	0.0	0.0
% of energy used from carbohydrates	69	100	100	100
METs kcal/hour	N/A	743	775	914
METs kcal/min	N/A	12.4	12.9	15.2
METs kcal/kg/min	N/A	0.2	0.2	0.2

Note. The values are averages taken from the last 6 minutes of the warm-up mile, the last minute of the 800 m, and the last 30 s of the 400 m.

Blair (2018) made a comparison of EE between a lower limb amputee using a running-specific prosthesis compared with a non-amputee similar in age, sex, and activity level. Results showed that the amputee, while using that specific running prosthesis, did not expend more energy than the matched control or the metabolic calculation. The triathlete with a Syme's amputation who participated in the current study ran wearing an Ossur Cheetah foot, designed to be lightweight and for gait efficiency. Although measured EE values were above predicted values, we would expect to see an even higher energy cost at the given intensity if she used a non- running-specific prosthesis.

These observations suggest that assessing the athlete performing in his or her specific mode of exercise with his or her specific gear is critical because an impairment can be more or less of a caloric burden in one mode of exercise versus another. Likewise, the type of sport equipment used, such as type of prosthetic, influences movement efficiency which can impact energy cost. We would expect to see the triathlete with the Syme's amputation expend higher amounts of energy while running when compared to the AB person accomplishing the same amount of work (Czerniecki et al., 2017; Gjovaag et al., 2018). However, a running-specific prosthetic can make energy cost lower than if she used a non-specific prosthetic, creating less of a difference between energy cost of an amputee and an AB person. The triathlete wore a running-specific prosthetic, which likely lowered her energy cost compared to if she wore her every-day prosthetic while running.

The results of this study showed that the RMR of the Syme's amputee was greater than that predicted by the Revised Harris-Benedict and the Mifflin-St Jeor equations. This is contrary to past studies that found that estimated RMR formulas used for AB individuals in amputees to overestimate by 5-32% (Schmalz et al., 2002; Buchholz et al., 2004). However, Jagmin et al. (2018) found that RMR prediction equations, including the Revised Harris-Benedict and the Mifflin-St Jeor formula, consistently underestimate RMR in male and female AB athletes. It was found that the prediction equation with the smallest mean difference (-165 kcals) was the Cunningham equation, which is based upon fat-free mass (FFM) instead of total body mass. Highly active individuals are expected to have higher metabolism at rest than sedentary individuals due to an increased amount of fat-free mass (Jagim et al., 2018). This could explain why the triathlete showed a higher RMR value than the prediction equations despite the physical impairment. This could mean that an increased metabolism from high levels of physical activity makes up for the lower energy cost of the missing or dysfunctional muscle mass of an amputee or paraplegic, respectively. Because we were unable to measure body composition for the triathlete, we could not use the Cunningham equation to estimate the triathlete's resting EE.

Goosey-Tolfrey et al. (2014) found that RMR prediction equations cannot be applied to amputees unless the amputation is small in magnitude. However, the magnitude of amputation is not defined to help determine when an amputee should not use resting rate prediction equations that are based off AB estimations (Goosey-Tolfrey et al., 2014). Because a Syme's amputation is only the removal of the foot from the ankle down, this could explain why the triathlete's RMR was higher than the predicted equation's estimate and what we might expect to see with other types of amputation. The energy requirements of the foot are only 1.5% of the whole body (Goosey-Tolfrey et al., 2014).

A strength of this study was that we assessed the individual energy needs of a para-athlete at rest and during her sport-specific workout at different exercise intensities in both a controlled lab setting and on the track. This provides valuable training information to the athlete and shows how the athlete's EE compares with the predictive equations for AB people. The primary limitation of this study was the sample size of one. Therefore, no generalizations can be made. Lastly, the participant was asked verbally before each visit to confirm abstinence from food (8 hours), alcohol, caffeine and vigorous exercise (24 hours) before the RMR test and alcohol (24 hours) before the ExEE tests; however, we cannot be certain of compliance.

CONCLUSION

This study found that in a Syme's amputee triathlete, while EE and substrate utilization during exercise are similar to that of an AB athlete, the triathlete expended energy at a higher rate than the predicted MET values in both cycling and running, with exception to the 400 m run. Measured RMR was higher than estimations from the Revised Harris-Benedict and the Mifflin-St Jeor equations for the triathlete with a Syme's amputation. Future studies should build upon these data by profiling athletes with similar impairments to assist in the generation of population-specific EE prediction equations. Defining energy requirements for para-athletes may aid in healthy lifestyles, body weight regulation, and performance enhancement.

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