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Resting Energy Expenditure in CrossFit® Participants: Predictive Equations versus Indirect Calorimetry

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ABSTRACT

Background: *CrossFit®* involves high-intensity functional movements and research has shown that the program increases metabolic rates in participants. **Objective:** To measure resting energy expenditure (REE) in CrossFit® participants using indirect calorimetry (IC) and to verify the most appropriate predictive equation to estimate REE. **Methods:** Overall, 142 CrossFit® participants (18–59 years; 91 [64.1%], women) underwent weight, height, waist circumference, and body mass index (BMI) measurements. Body composition was evaluated using a portable ultrasound system (BodyMetrix®). REEs were measured (mREE) by IC and predicted by six different equations (pREE): Harris-Benedict, World Health Organization (WHO), Henry and Rees, Cunningham (1980 and 1991), and Mifflin–St. Jeor. **Results:** The mean age was 33.0 (6.3) years, with no significant difference between men and women; mean mREE, 1583.2(404.4) kcal/d; and pREE, 1455.5(230.9) to 1711.3(285.5) kcal/d. The best REE predictive equations for this population were Cunningham (1991) (P=0.338), WHO (P=0.494), and Harris-Benedict (P=0.705) equations. The Harris-Benedict equation presented a smaller difference compared with IC [12.9(307.6) kcal], the Cunningham (1991) equation showed improved adequacy (102.5%), and the WHO equation presented highest accuracy (59.9%). The equations that were closest to the mREE were the Harris-Benedict for women and the WHO equation for men. **Conclusion:** Therefore, for CrossFit® participants, the REE can accurately be predicted with the Cunningham (1991), WHO, and Harris-Benedict equations.

Key words: Basal Metabolism, Energy Expenditure, Indirect Calorimetry, Athletes, Body Composition

INTRODUCTION

CrossFit®, a high-intensity functional training model created by Greg Glessman, requires cardiovascular physical ability and capacity, endurance, strength, flexibility, power, speed, coordination, agility, balance, and precision in participants. Each CrossFit® workout is called a WOD, workout of the day, and comprises a combination of exercises including Olympic gymnastics, weightlifting, and aerobic exercises. All the movements need to be performed within specified time limits, quickly or repetitively, and almost without rest (Claudino *et al*., 2018; Souza *et al*., 2021). To achieve good training performance, the participant needs an adequate energy intake. An individual's total energy expenditure (TEE) is usually composed of three components: thermal effect of food, physical activity energy expenditure, and basal energy expenditure (BEE) (Levine, 2005; Psota & Chen, 2013). The BEE corresponds to basal energy expended by the body, representing 60–75% of the TEE in sedentary people or 45–60% of the TEE in athletes and participants of physical activity, approximately (Levine, 2005; Oshima *et al*., 2017). But this basal condition is hard to assess in clinical practice. For this reason, resting energy expenditure (REE) is utilized since it is simpler to evaluate than the BEE, presents a very small difference (3 to 10%) from the basal condition and it can be evaluated with the volunteer resting in a thermoneutral room (Levine, 2005). Errors in the determination of REE can impair performance and cause injuries and endocrine changes, in addition to causing menstrual dysfunction in women (Thein-Nissenbaum *et al*., 2011). REE contains an expansive intrapersonal or interpersonal variety depending on size, body composition, energy adjust, age, sex, and hereditary qualities. Fat-free mass (FFM) is detailed as the most grounded determinant of REE (Psota & Chen, 2013). When evaluating the REE, indirect calorimetry (IC) is considered

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the gold-standard strategy (Delsoglio *et al*., 2019). It is a non-invasive technique that assesses the REE by analyzing oxygen and carbon dioxide gases. To calculate the overall energy required, it is assumed that all the oxygen expended is utilized to oxidize the energy substrates which all the created carbon dioxide is eliminated with whereas breathing (Levine, 2005; Psota & Chen, 2013; Oshima *et al*., 2017). As the calorimeter is a more expensive device, the application of this test in the clinical practice is difficult; therefore, REE predictive equations are widely used and reliable in healthy individuals (Redondo, 2015; Delsoglio *et al*., 2019). Thus, our objective was to evaluate REE by IC in CrossFit® participants and to determine the safe and reliable REE predictive equations in these individuals.

METHODS

Study Design

This cross-sectional study was carried out with CrossFit® participants aged >18 years in the city of Fortaleza, Ceará, Brazil, from January 2014 to March 2019. This research was endorsed by the Ethics Committee of our institution (# 1,864,725). All participants signed an informed consent document.

Participants

In our convenience sample, inclusion criteria considered for selection were individuals of both sexes who have been practicing CrossFit® for at least 1 year, 5 times a week, and were aged between 18 and 59 years. Participants were invited by researchers at gyms (CrossFit® boxes) in the city of Fortaleza, Ceará, Brazil. Individuals who did comply with the IC protocol or did not meet inclusion criteria were excluded.

Procedures

The anthropometric assessments of weight and height were performed using the standardization characterized by the World Health Organization (WHO). Weights were measured employing a weighing-machine (Welmy®), and heights were evaluated using a stadiometer (Welmy®). Weights and heights were utilized to estimate body mass index (BMI) (WHO, 2000).

Body composition was assessed using a portable ultrasound system (BodyMetrix®), and the anatomical points of the triceps, chest, middle axillary, suprailiac, subscapular, abdominal, and middle thigh were examined, which were standardized using the manual of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart *et al*., 2011). Waist circumference (WC) was also measured using ISAK standardization (Stewart *et al*., 2011). Body fat percentages were estimated automatically by the BodyMetrix® body analysis software based on the equations of Jackson & Pollock (1978) and Jackson, Pollock, & Ward (1980), for men and women, respectively, both using 7 skinfold thickness.

REEs were evaluated by IC measured by the Korr® MetaCheck calorimeter, with individuals fasting for at least 5 h and resting for 30 min before starting the assessment. The participants were informed to not realize exercise one day before the evaluation. Additionally, smoking, consumption of caffeine (coffee, tea, supplements, chocolate) and other types of stimulants was prohibited for 24 h before the evaluation. The equipment was turned on for 15 minutes before calibration and stabilization tests, following manufacturer's instructions. All the tests were assessed in a silent room with a controlled temperature between 23 and 25 °C. Each test lasted for 30 min, and the primary 5 minutes were ignored to guarantee satisfactory acclimatization. The participants were sitting and using a rigid breathing mask. Additionally, the volunteers were instructed not to speak or sleep during the assessment and to avoid yawning or becoming agitated (Oshima *et al*., 2017; Compher *et al*., 2006; Haugen, Chan, & Li, 2007). REE was based on consumption of oxygen (VO_2) and carbon dioxide production (VCO_2), using the Weir equation (Weir, 1949).

The REE evaluated by IC was defined as the measured REE (mREE) and it was compared with six predictive equations that are commonly used to evaluate this parameter (Table 1).

Statistical Analysis

Statistical investigations were conducted utilizing the SPSS®, version 19.0 for Windows (SPSS Inc., Chicago, IL, USA). Normality was evaluated by Kolmogorov–Smirnov

Table 1. Predictive equations of resting energy expenditure (REE)

Reference	Equation
Harris-Benedict (1918)	Male: REE=66.4730+13.7516 x Weight (kg) + 5.0033 x Height (cm) – 6.7550 x Age (y) Female: REE=655.0955+9.5634 x Weight (kg) + 1.8496 x Height (cm) – 4.6756 x Age (y)
World Health Organization WHO (1985) Only weight	Male: Age 18-30 → REE=15.3 x Weight (kg) + 679 Female: Age 18-30 → REE=14.7 x Weight (kg) + 496 Male: Age 30-60 → REE=11.6 x Weight (kg) + 879 Female: Age 30-60 → REE=8.7 x Weight (kg) + 829
Henry & Rees (1991)	Age 18-30 (males) → REE = (0.056 x Weight (kg) + 2.800) x 239 Age 18-30 (females) → REE = (0.048 x Weight (kg) + 2.562) x 239 Age 30-60 (males) → REE = (0.046 x Weight (kg) + 3.160) x 239 Age 30-60 (females) → REE = (0.048 x Weight (kg) + 2.448) x 239
Cunningham (1980)	REE=500+22 x Lean Body Mass (kg)
Cunningham (1991)	REE=370+21.6 x Fat-Free Mass (kg)
Mifflin-St. Jeor (1990)	Male: REE=10 x Weight (kg) + 6.25 x Height (cm) – 5 x Age (y) + 5 Female: REE=10 x Weight (kg) + 6.25 x Height (cm) – 5 x Age (y) – 161

test. Qualitative parameters were presented using absolute and relative frequencies. Quantitative parameters with normal distribution were presented as means and standard deviations, and were compared using the paired Student's *t*-test. Non-normally distributed parameters were expressed as median, minimum and maximum and were compared using the non-parametric Wilcoxon test. The Bland–Altman plots were used to identify the concordance between the predictive equations and indirect calorimetry. In our study, *P*-values <0.05 were considered statistically significant.

RESULTS

In this study, the REEs of 142 CrossFit participants were evaluated, including 90 women (63.4%) and 52 men (36.6%). No volunteers were excluded based on exclusion criteria. The age of participants ranged from 18-59 years, with an average of 33.0(6.3) years of age, with no difference between the sexes (*P*=0.795). Table 2 presents the anthropometric, body composition, and IC assessment data of the participants. No attempt was made to match body composition and therefore the differences between men and women were expected.

The comparison of the REEs for the CrossFit® participants evaluated in our study is presented in Table 3. The Harris-Benedict (1918), WHO (1985), and Cunningham (1991) equations were the ones that came closest to the REE value obtained by IC (*P*>0.05). In addition, these three equations showed the smallest differences in calories as compared to IC and the best accuracies (number of individuals with a maximum variation of 10% compared to indirect calorimetry).

Stratified by sex (Table 4), men showed higher REE compared to women both in IC and in all the predictive equations (*P*<0.001). Among men, the best predictive equations were the WHO (1985), Cunningham (1991), Harris-Benedict (1918), and Mifflin–St. Jeor (1990), in that order. Mifflin–St. Jeor (1980) equation showed a greater difference in calories compared to IC. Among women, the best predictive equations were the Harris-Benedict (1918), WHO (1985), and Cunningham (1991), in that order. The Bland-Altman plots are presented in Figure 1.

DISCUSSION

Our study compared the REEs evaluated by IC with those estimated by predictive equations in CrossFit® participants.

Table 2. Anthropometric, body composition, and indirect calorimetry data of the sample

Parameters	TOTAL (n=142)	MEN (n=52)	WOMEN (n=90)	*P-value*
Age (years) Mean (SD)	33.0 (6.3)	33.1 (5.7)	32.8 (6.8)	0.795
Weight (kg) Mean (SD)	70.1 (14.7)	83.5 (12.3)	62.3 (9.4)	<0.001
Height (m) Mean (SD)	1.68 (0.08)	1.75 (0.05)	1.63 (0.05)	<0.001
BMI (kg/m^2) Mean (SD)	24.7 (3.5)	27.1 (3.0)	23.3 (2.9)	<0.001
Waist Circumference (cm) Mean (SD)	76.5 (9.7)	85.4 (7.6)	71.2 (6.4)	<0.001
Body fat percentage (%) Median (min-max)	21.8 (7.2 – 40.6)	14.7 (7.2 – 30.8)	25.3 (8.1 – 40.6)	<0.001
Fat mass (kg) Mean (SD)	15.1 (6.5)	13.9 (7.3)	15.9 (5.9)	0.099
FFM (kg) Mean (SD)	55.1 (13.0)	69.6 (7.5)	46.4 (5.7)	<0.001
REE (kcal/d) Mean (SD)	1583.2 (404.4)	1884.7 (416.3)	1403.4 (258.4)	<0.001
REE adj by weight (kcal/d) Median (min-max)	22.8 (9.0 – 35.8)	22.8 (9.0 – 35.8)	22.7 (12.7-31.2)	0.953
REE adj by FFM (kcal/d) Median (min-max)	29.2 (10.5 – 40.8)	26.9 (10.5 – 40.8)	30.6 (15.2 – 40.2)	<0.001
REE adj by squared height (kcal/d) Median (min-max)	538.9 (248.9 – 996.0)	603.4 (248.9 – 996.0)	516.7 (261.8-705.5)	<0.001
VO2 Mean (SD)	224.5 (60.9)	268.5 (62.4)	198.6 (40.7)	<0.001
FeO2 Median (min-max)	17.0 (15.7 – 18.4)	16.8 (16.1 – 18.3)	17.1 (15.7 – 18.4)	<0.001
FR Median (min-max)	15.6 (5.7 – 28.4)	14.9 (6.8 – 23.0)	16.3 (5.7 – 28.4)	0.168

SD: standard deviation; BMI: body mass index; FFM: fat-free mass; FR: respiratory frequency; adj: adjusted.

Table 3. REE, differences, and adequacy between indirect calorimetry and the predictive equations

Method	REE (kcal/d)		Difference (kcal/d)	Adequacy of Predicted REE - %(n)			
	Mean (SD)	*P*-value*	Mean (SD)	Underestimated <90%	Accurate 90 – 110%	Overestimated >110%	Mean (SD)
Indirect calorimetry	1583.2 (404.4)	-	-	-	-		-
Harris-Benedict (1918)	1570.4 (268.9)	0.705	12.9 (307.6)	24.0 (n=34)	55.6 (n=79)	20.4 (n=29)	103.5 (25.6)
WHO (1985)	1563.8 (271.7)	0.494	19.5 (304.2)	21.8 (n=31)	59.9 (n=85)	18.3 (n=26)	103.1 (26.0)
Henry & Ress (1991)	1455.5 (230.9)	<0.001	127.3 (303.4)	43.0 (n=61)	45.8 (n=65)	11.3 (n=16)	96.1 (23.7)
Cunningham (1980)	1711.3 (285.5)	<0.001	-128.0 (292.9)	11.3 (n=16)	43.7 (n=62)	45.1 (n=64)	112.7 (27.4)
Cunningham (1991)	1559.2 (280.4)	0.338	24.0 (292.8)	23.9 (n=34)	57.0 (n=81)	19.0 (n=27)	102.5 (25.0)
Mifflin-St.Jeor (1990)	1478.6 (274.2)	<0.001	104.6 (316.6)	35.9 (n=51)	50.7 (n=72)	13.4 (n=19)	97.3 (24.5)

SD: standard deviation; WHO: World Health Organization; *significance between indirect calorimetry and predictive equations.

Table 4. REE between indirect calorimetry and predictive equations by sex

Method	MEN (n=52)		WOMEN (n=90)		*P-value**
	Mean (SD)	*P-value*#	Mean (SD)	*P-value*#	
Indirect Calorimetry (kcal/d)	1884.7 (416.3)	-	1403.4 (258.4)	-	<0.001
Harris-Benedict (1918)	1869.1 (188.2)	0.791	1396.9 (107.5)	0.781	<0.001
WHO (1985) (only weight)	1878.0 (154.1)	0.908	1379.6 (104.8)	0.306	<0.001
Henry & Ress (1991)	1708.2 (150.6)	0.003	1306.7 (107.8)	<0.001	<0.001
Cunningham (1980)	2031.3 (165.4)	0.010	1521.1 (126.4)	<0.001	<0.001
Cunningham (1991)	1873.4 (162.4)	0.837	1372.6 (124.1)	0.185	<0.001
Mifflin-St.Jeor (1990)	1770.8 (147.4)	0.053	1309.0 (163.5)	<0.001	<0.001

SD: standard deviation; WHO: World Health Organization; *: significance between men and women; #: significance between predictive equations and indirect calorimetry.

The predictive equations of REE have not been validated in this population, previously. The American College of Sports Medicine – ACSM recommends Cunningham (1980) and Harris-Benedict (1918) equations in sedentary, active populations and in athletes, even though these equations were not developed for the athletic individuals (Thomas, Erdman, & Burke, 2016). The Harris–Benedict (1918) equation was proposed in a study with 136 men, 103 women, and 94 children of healthy North American origin. This is the most commonly used equation, specifically in clinical assistance, to estimate the energy needs of healthy individuals or those with the most diverse pathologies. This equation tends to overestimate the REE (Warlich & Anjos, 2001; Frankenfield *et al*., 2003), but this was not observed our study.

In this study, most equations underestimated the REE measured by IC, except for the Cunningham (1980), which overestimated the REE ($P < 0.001$). The equations of Henry & Ress (1991) and Mifflin–St.Jeor (1990) had the largest underestimation of the REE ($P < 0.001$). The Harris-Benedict (1918) had the most similar value to the measured by IC, followed by the WHO (1985) and Cunningham (1991).

The Harris–Benedict (1918) equation likely performed better because it contains a larger number of variables that influenced the REE (body mass, height, and age). Body mass alone can affect the REE variance by approximately 50%; in addition, when age, height, and sex are included, the variance can rise to 71% (Muller & Soares, 2018). The original sample associated with the Harris-Benedict equation was quite diverse, as was our sample, which may have helped with the approximated values.

In a study of 103 Dutch participants (18–35 years old) of different sports, the REE was accurately predicted by the Cunningham formula (1980), including only fat-free mass (FFM) as a variable, suggesting that FFM is a significant determinant of resting metabolism. In addition, weight and stature probably do not predict the REE well in athletes due to the difference in body compartments when compared to the general population (Haaf & Weijs, 2014). Thompson & Manore (1996) analyzed REEs of 37 highly trained endurance athletes and found that Cunningham's equation (1980) was also the best predictor of REE in both men and women. FFM is the best determinant of REE variability

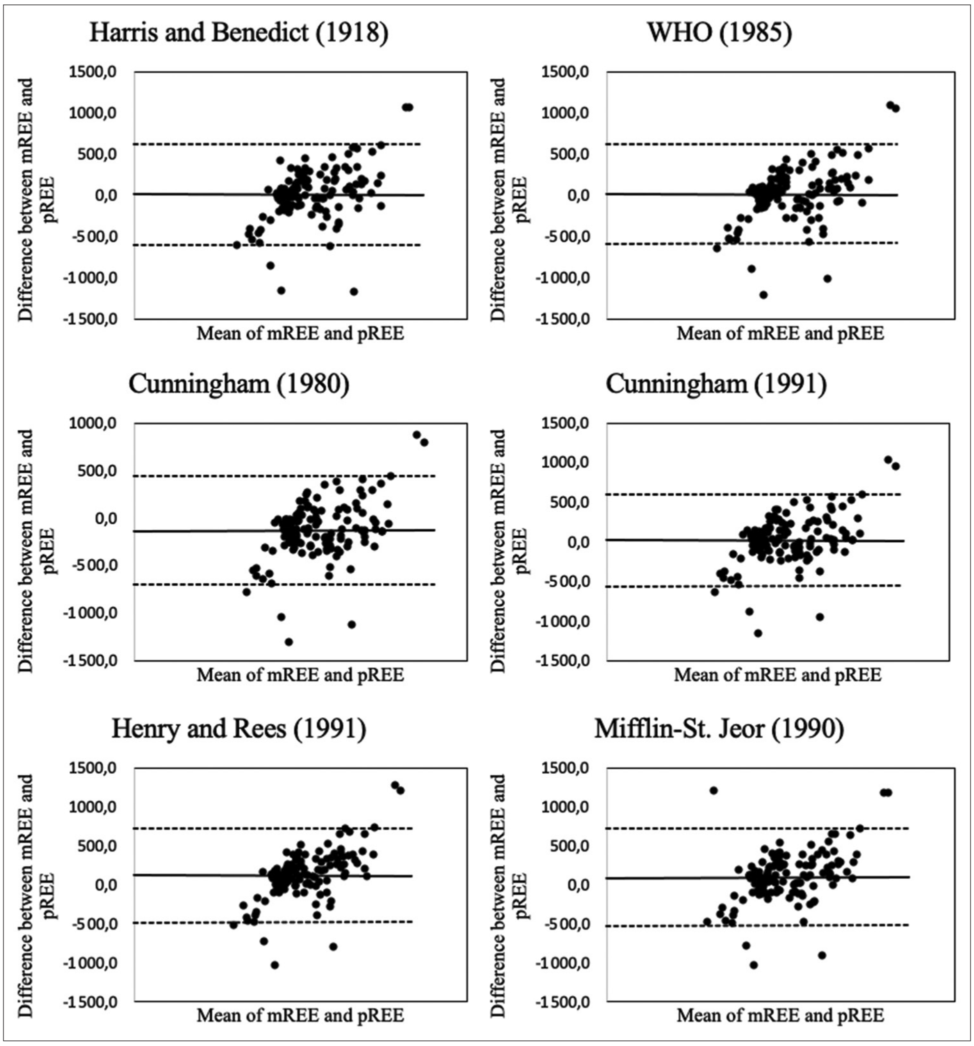

Figure 1. Bland-Altman plots comparing measured REE (mREE) by IC and predictive REE (pREE) using equations

(Cunningham, 1980; Cunningham, 1991; Thompson & Manore, 1996; Haaf & Weijs, 2014; Muller & Soares, 2018).

In the present study, the Cunningham equation (1980) overestimated the REE in both men and women who practiced CrossFit®, while the Harris-Benedict equation was the best predictor of REE in women who practiced CrossFit®, and the WHO (1985) equation was the best for men. Both equations consider the individual's body mass. Although Henry (2005) and Warlich & Anjos (2001) showed that the WHO (1985) equation overestimated the REE in several populations, this was not observed in our study.

In Brazil, a study compared REE evaluated by IC with four predictive equations in 174 bodybuilders aged 18–59 years living in Brasília, Brazil. All the equations underestimated the REE in this population, but the Harris-Benedict (1918) and WHO (1985) equations gave the closest values (Pereira *et al*., 2008). These results are similar to ours.

When comparing more experienced athletes with CrossFit® participants, similarities were observed between the metabolic rates (only 20 kcal/day difference); however, the athletes had higher FFMs, lower body fat percentages, lower fat masses, and more favorable body compositions associated with sustaining high intensity effort (Mangine, Stratton *et al*., 2020). These data corroborate the findings of Tibana *et al*. (2017) and Mangine, Tankersley *et al*. (2020), in which both athletes and CrossFit® participants with lower body fat percentages showed better performances in WODs, suggesting body composition to be a predictor of performance.

The REE of our sample is very similar, in absolute values, to that of individuals belonging to the control group of Mangine, Stratton *et al*. (2020) study [1583.2(404.4) kcal/d; 1572(356) kcal/d], the participants of which were considered to be physically active; they practiced resistance and underwent cardiovascular training regularly. The REE of our sample was lower as compared to the REEs of more experienced athletes [1788(232) kcal/d] and CrossFit® participants [1768(407) kcal/d] from the same study. The rankings in the Open championships and participations in both regional and Games championships distinguished more experienced athletes from CrossFit® participants. Furthermore, the physiological differences presented by the most experienced athletes were associated with the training habits of the last six months (Mangine, Stratton *et al*., 2020). Athletes with higher training volumes follow a different worksheet than conventional CrossFit® box students, and they often do two training sessions a day. This high training volume improves lean mass, increases performance, and increases the skeletal muscle mass. An improvement in lean mass is closely linked to an increase in the REE (Cavedon *et al*., 2020).

On comparing the sexes, the REE was significantly higher in men [1884.7(416.3) kcal/d] than that in women [1403.4(258.4) kcal/d]; however, on adjusting for weight, the difference was not founded (P=0.953), and on adjusting for FFM, this difference remained significant (P<0.001). Men also had higher body masses, heights, FFMs, and BMIs and lower body fat percentages (P<0.001). The greater percentage of FFM in men may have contributed to their greater REEs. This result was expected as men have more lean mass and less body fat than women. FFM is a component of body mass that consumes more oxygen; therefore, it is more metabolically active. Each kilogram of lean tissue was found to exert five times more influence on the basal metabolic rate than that exerted by each kilogram of adipose tissue (Warlich & Anjos, 2001).

Men had a mean BMI higher than that of women (P<0.001). Therefore, they were classified as overweight [27.1(3.0) kg/m^2] whereas women were classified as normal weight [23.3(2.9) kg/m^2], according to the WHO cut-off points (WHO, 2000). However, BMI does not discriminate between fat mass and FFM; therefore, this limitation needs to be emphasized.

When considering the contrasts in the body composition, sex and physical training status, equations that take into account body mass, (i.e., the Harris-Benedict), seem to provide a better prediction for the clinical population. For athletic individuals, equations using FFM seem to provide a better prediction. This may be due to their higher FFM and lower FM.

There are some limitations in our research. We utilized a convenience sample and therefore our sample is not representative of all CrossFit® participants. Future studies should consider a different recruitment approach to improve generalizability. Previous research has identified that underestimation or overestimation of REE can induce mistakes in the calculation of energy needs, which may adversely affect the health of individuals (Nattiv, 2000; Wentz *et al*., 2012).

In summary, this study is to the best of our knowledge the first to investigate the reliability of predictive equations for energy demands when compared to IC among CrossFit® participants. The best fit equations in this population were the Harris-Benedict in women, and the WHO (1985) in men. Access to IC equipment is often prohibitive because of the cost and professional training required for implementation. These equations will provide a user-friendly approach for determining the energy demands and subsequent caloric needs in this population of CrossFit® participants.

CONCLUSION

In this study, we observed an underestimation and/or overestimation of the REE by the predictive equations in comparison with IC. The equation that was closest to the REE evaluated by IC was the Harris–Benedict equation for women and the WHO equation for men. New studies can propose and develop specific equations for this population, aiming to assist nutritionists in adequate food planning.

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