A comparison of energy expenditure equations for basal-equivalent activities

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Abstract

Introduction: Resting energy expenditure (REE) represents the largest component of total energy expenditure and is a major contributor to energy balance. Over the past several decades, numerous REE equations have been developed targeted to different population groups. However, the generation of standardized equations for predicting energy expenditure, to be applied to every healthy individual, is still subject to research. Purpose: This study aims to test existing predictive equations for basal energy requirements and based on a comparison of their results and measured values, to determine the most appropriate to the characteristics of the studied group. Methodology: Thirty participants (age 30,37 ± 5,50) performed a sequence of five activities chosen to represent basal, light and moderate intensities. The included three basal-equivalent tasks were analyzed in this study. During each trial, oxygen consumption was measured by a portable metabolic system (K_4b^2). From a previously developed literature research, equations were selected to estimate energy requirements. Calculations and values obtained from oximetry were compared. Results and Discussion: Retrieved predictive equations were filtered to 21 relevant equations from 15 authors. When observing general results, most participants showed the equation proposed by Korth (based on weight, height, sex, and age) to be the one predicting values with a better approximation to K_4b^2, followed by the Haaf&Weijs' equation, based on fat-free mass (FFM). From the individual analysis, Korth's equation proved to work well for men in most cases and poorly for women. Correspondingly, Haaf&Weijs equation gave better results for females. Specifically, better approximations were obtained within males participants. Finally, the associated deviations from measured values indicate more reliable results than a Level 1 (two with better accuracy than a Level 2) of the assessment approaches, for energy consumption while working, referred in the ISO 8996:2004 standard. Conclusions: Through this study, Korth (based on weight, height, sex, and age) and Haaf&Weijs (based on FFM) equations proved to be the most accurate. As a result, since body composition measurement is not always possible, the equation of Korth is advised for use in a young subjects' sample with similar overall characteristics to the sample hereby presented. Future studies should be developed to test equations within bigger samples and propose a new regression model that better adapts to the studied population.

Keywords: Resting energy expenditure, Energy requirements, Energy expenditure estimations.

INTRODUCTION

The accurate prediction of energy requirements for healthy individuals has many useful applications (Mifflin et al., 1990). Various studies associated with energy expenditure have been conducted within different contexts. From the occupational perspective, it has also been proven of great utility for ergonomics, safety, and health of workers (Lucena, Guedes, Vaz, & Silva, 2018). Specifically, resting energy expenditure (REE) contributes to 60-70% of daily energy requirements. REE is the maintenance energy cost of the body in rest under steady state conditions. This is different from the minimal energy cost. Energy expenditure can, for example, be lower during sleep or during undernutrition (ten Haaf & Weijs, 2014). REE can be measured through indirect calorimetry or estimated using predictive equations. The gold standard to determine the REE is the measurement by indirect calorimetry (ISO, 2004; Lucena et al., 2018). However, procedures for direct measurements are complex, expensive and not feasible for frequent and timely individual use (Sabounchi, Rahmandad, & Ammerman, 2013; ten Haaf & Weijs, 2014). As a result, several mathematical equations, mostly developed by regression methods, have been adopted as a major technique for this matter. Nevertheless, there is not an agreement on which equation is most suitable to which situation or to which population's characteristics. Therefore, this study aims to validate existing resting energy expenditure predictive equations and, based on obtained results, to identify the equations that better estimate energy requirements for every tested situation.

METHODOLOGY

Most of the experiments were performed at the Laboratory on Prevention of Occupational and Environmental Risks (PROA) at the Faculty of Engineering of the University of Porto, while the rest were executed at the Faculty facilities. The volunteers were fully informed of the details of the experimental procedures and were briefed on purpose, potential risks and benefits of the experiences. Written consent was read and signed by them prior to starting the trials.

Participants

Thirty participants volunteered for the study. Their physical characteristics are summarized in Table 1.

Table 1. Subjects' characteristics

	Total (n 30)		Male (n 15)		Female (n 15)	
Variables	Mean	SD	Mean	SD	Mean	SD
Age (years)	30,37	5,50	31,00	6,23	29,73	4,79
Height (cm)	171,07	9,78	177,27	8,11	164,87	7,08
Weight (kg)	70,73	14,19	79,21	13,85	62,26	8,47
BMI (kg/m^2)	23,86	3,67	24,86	3,57	22,85	3,59
FFM (kg)	52,96	13,83	62,96	12,09	42,95	5,95

Materials and equipment

The experiments were mostly conducted inside a climatic chamber (FITOCLIMA 25000EC20). Body composition was assessed using bioelectrical impedance analysis (Body Composition Analyzer InBody230). Energy expenditure (EE) was measured from pulmonary gas exchange using a breath-by-breath portable gas analyzer (Cosmed K_4b^2, Rome, Italy).

Experimental design

Before testing, participants had their height and weight measured (in light clothing, without shoes). Later, they performed various lifestyle and simulated working activities. Activities were chosen to test the multiple equations found in the literature at the time of verifying the relevance of the measurements for occupational settings. The designed protocol has 5 activities (Table 2). Nevertheless, this present work will focus on the three found to be equivalent to basal conditions (1, 2, 5) aiming to test the applicability of REE equations (found in the available scientific literature) to the studied population's characteristics.

Literature search and filtering

A comprehensive search of the literature was performed to identify all available studies that predict energy expenditure, based on anthropometric data and actigraphy, and develop an investigation within healthy participants. Consulted databases included: Academic Search Complete, Scopus, Web of Science, Science Direct, PubMed, Francis and Taylor, and Medline. Search terms were selected so that any publication, which finds a prediction model for energy expenditure, is included. Retrieved articles were reviewed in two steps. First, abstracts were reviewed and items not fitting were excluded. Then, the full-text for the remaining articles were obtained and analyzed to select the articles that included an equation based on the above criteria. In a parallel process, reference tracking helped to identify additional studies not retrieved through an automated search.

Table 2. Protocol of activities.

Activity Sequence	Description	Duration (min)	Type of Activity
1	Lying.	10	Basal
2	Sitting, doing computer work.	5	Basal
3	Standing, playing with cards.	5	Multitask
4	Standing, moving up and down a 2kg-load, metronome: 40 bits/min.	5	Multitask
5	Sitting, watching a video.	5	Basal

RESULTS

Selected equations

From the referred literature search, initial 124 potential approaches were identified for application within this study. After retrieving and analysis, they were reduced to 21 relevant equations from 15 authors, aimed for predicting energy requirements for resting or basal activities (De Lorenzo et al., 2001; Food, Organisation, & Committee, 1973; Harris & Benedict, 1919; Henry, 2005; Korth et al., 2007; Liu, Lu, & Chen, 1995; Livingston & Kohlstadt, 2005; Mifflin et al., 1990; Miyake et al., 2011; Müller et al., 2004; Owen et al., 1987; Owen et al., 1986; Roza & Shizgal, 1984; ten Haaf & Weijs, 2014; Wang et al., 2000; Yang et al., 2010). These equations are respectively presented in Table 3. For calculations, they were all converted for uniform results in kcal/min.

Table 3. Predictive equations for resting activities.

Author	Equations	
	Male	**Female**
Harris-Benedict	66.4730 + 13.7516*w + 5.0033*h - 6.7550*a	655.0955 + 9.5634*w + 1.8496*h - 4.6756*a
Owen	879 + 10.2*w	795 + 7.18*w
Mifflin	10*w + 6.25*h - 5*a + 5	10*w + 6.25*h - 5*a - 161
Liu	13.88*w + 4.16*h - 3.43*a - 112.40*s + 54.34 (for s: male=0 and female=1)	
Ganpule	(0.0481*w + 0.0234*h - 0.0138*a - 0.4235)*1000/4.186	(0.0481*w + 0.0234*h - 0.0138*a - 0.9708) *1000/4.186
FAO/WHO/UNU (weight)	0.0640*w + 2.84 ; 18<=a<30	0.0615*w + 2.08 ; 18<=a<30
	0.0485*w + 3.67 ; 30<=a<60	0.0364*w + 3.47 ; 30<=a<60
FAO/WHO/UNU (weight-height)	64.4*w - 113.0*h + 3000 ; 18<=a<30	55.6*w + 1397.4*h + 146 ; 18<=a<30
	47.2*w + 66.9*h+3769 ; 30<=a<60	36.4*w - 104.6*h + 3619 ; 30<=a<60
Henry	14.4*w + 313*h +113 ; 18<=a<30 (h in meters)	10.4*w + 615*h - 282 ; 18<=a<30 (h in meters)
	11.4*w + 541*h -137 ; 30<=a<60 (h in meters)	8.18*w + 502*h -11.6 ; 30<=a<60 (h in meters)
Muller Model 1	(0.047*w + 1.009*s - 0.01452*a + 3.21)*238.85 (for s: male=1 and female=0)	
Muller Model 2	(0.05192*FFM + 0.04036*FM + 0.869*s - 0.01181*a +2.992)*238.85 (for s: male=1 and female=0)	
Livingston	293*w^0.4330 - 5.92*a	248*w^0.4356 - 5.09*a

Author	Equations	
	Male	Female
Korth	41.5*w - 19.1*a + 35*h + 1107.4*s - 1731.2 (for s: male=1 and female=0)	
De Lorenzo	53.284*w + 20.957*h - 23.857*a + 487	46.322*w + 15.744*h - 16.66*a - 944
Yang Model 1	277 + 89*w + 600*s (for s: male=1 and female=0)	
Yang Model 2	105*w - 58	69*w + 1335
Wang	24.6 * FFM + 175	
Roza	88.362 + 4.799*h + 13.397*w - 5.677*a	447.593 + 3.098*h + 9.247*w - 4.330*a
Hhaf & Weijs	22.771*FFM + 484.264	

s=sex; w=weight (kg); h=height (cm); a=age (years); FFM=fat-free mass (kg); FM=fat mass (kg)

Experimental results

Considering the differences between measured and predicted results, average outcomes revealed that the equation which better adapted to the three evaluated activities was the one proposed in Korth's study (Korth et al., 2007). Fig. 1 shows mean measured values from all participants and the estimations that most accurately approximated to the oximetry values.

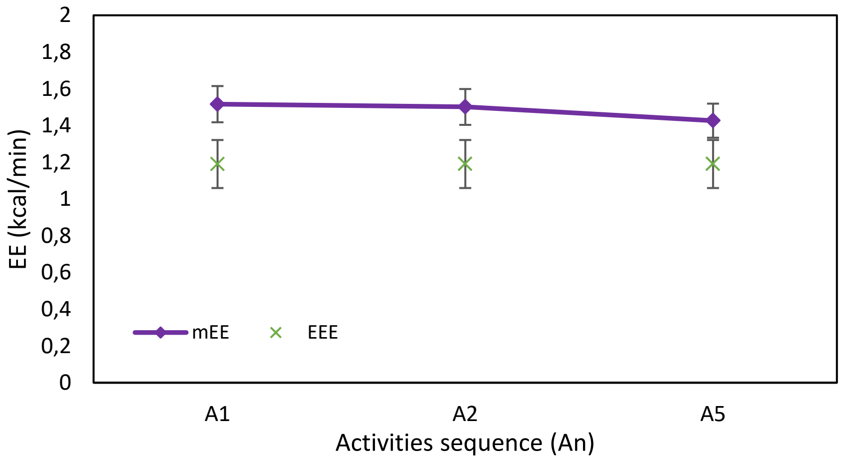

Figure 1. Measured EE (mEE) vs. Estimated EE (EEE) per activity

Figure 2 and Figure 3 present the average results for men and women, respectively. Korth's equation proved to be most accurate for males while the Haaf&Weijs' model gave better results for females.

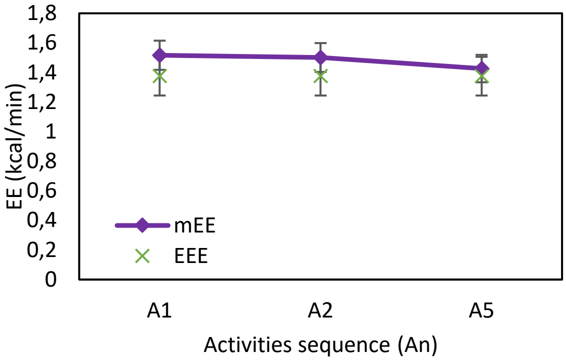

Figure 2. Measured EE (mEE) vs. Estimated EE (EEE) in males

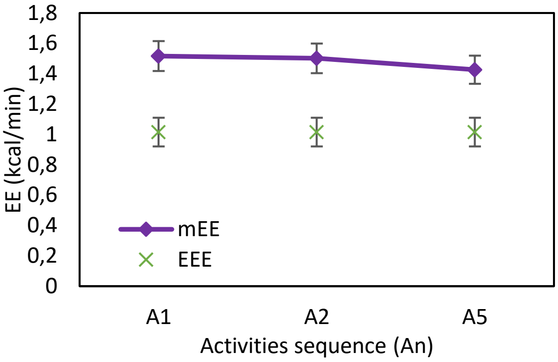

Figure 3. Measured EE (mEE) vs. Estimated EE (EEE) in females

DISCUSSION

Through this study, a comprehensive summary of available REE equations was gathered and, their predictive power was tested within laboratory trials. As a result, it was possible to identify the equations that better estimate energy requirements when compared to measured values from a gold standard (K_4b^2). From a general perspective, most participants evidenced Korth's equation to be the one predicting values with a better approximation to K_4b^2, followed by the Haaf&Weijs' equation. Overall, better outcomes were observed with equations combining more than one anthropometric variable. Those applying only body weight for example (Food et al., 1973; Owen et al., 1987; Owen et al., 1986), evidenced the biggest differences. In fact, the best-obtained results (Korth and Haaf&Weijs) were based on a combination of various variables. Korth proposes a formula considering weight, height, sex, and age, while Haaf&Weijs' model is based on fat-free mass (FFM). As FFM can be expressed by a function of age, sex, height, and body weight, it was demonstrated that compared to FFM, body weight alone was inferior as a predictor of REE and its predictive power can be substantially improved by the inclusion of height, sex and age (Korth et al., 2007). Notably, from the individual analysis, Korth's equation proved to work well for men in most cases and poorly for women. Correspondingly, Haaf&Weijs equation gave better results for females. Despite all, they both were responsible for the majority of the most accurate results. For the few cases in which different equations were identified, Korth and Haaf&Weijs equations still appeared as the second best. As Korth et al. (2007) anticipated, choosing the appropriate resting predictive equations should be based on the agreement of the study population and protocol with the characteristics of the reference population and study protocol used for generation of the equation. In that regard, it was evidenced that anthropometrics from Korth's study and only male participants from this study were comparable, which can explain why the equation worked well mostly for the male proportion of the sample. What is more, observing Figures 2 and 3, results from the male proportion of the sample demonstrate better approximations than both, the general and females' outcomes. Correspondingly, the significant differences identified on some anthropometric characteristics in females populations (age, height, and FFM) clarify the big variations between EE estimations and measurements (Fig. 3) within this group. Specifically, FFM explains 60-70% of the inter-individual variance in REEs which can justify their distance from measured values, even considering the associated error reported by the authors. In that last respect, for this study, comparisons were made considering stated deviations from both equations and reference equipment. Korth indicates a standard estimated error of 788 kJ/day (approximately 0.13 kcal/min) while Haaf&Weijs reports a deviation of 0.57 MJ/day for females (approximately 0.095 kcal/min). On the other hand, considering the error from the K4b2, the manufacturer claims a 2% but within several validation studies, variations evidence percentages of up to 6.5% (Ross, ALDuhishy, & González-Haro, 2019). For this work, this last maximum value was applied. Despite considering the referred error limits, only the male proportion of the sample proved to provide representative predictions. Thus, future studies need to be performed within bigger samples. Finally, the associated deviations from measured values indicate more reliable results than a Level 1 (two with better accuracy than a Level 2) of the assessment approaches (for energy consumption while working) referred in the ISO standard (ISO, 2004). Estimated outcomes evidenced approximately 25, 20 and 16 % of error for activities one, two and five, respectively. As a result, the applicability of predictive equations was demonstrated but needs to be validated within bigger samples to corroborate their proximity to the ranges referred to in the standard.

Limitations

The number of volunteers must be higher in order to support the reliability of the results and potentially reduce obtained deviations. Furthermore, the addition of more time within each designed activity would also allow a better comparison of outcomes.

CONCLUSIONS

To facilitate the process of energy expenditure estimation, several equations for basal-equivalent activities were tested within a laboratory experience. Based on the obtained results, the most accurate predictions to the studied population were determined. In general, Korth (weight, height, sex and age) and Haaf&Weijs (based on FFM) equations proved to be more accurate. As a result, since body composition measurement is not always possible, the equation of Korth is advised for use in a young subjects' sample with similar overall characteristics to the sample hereby presented. As a consequence of the specificity of a REE equation, a researcher has to deal with the trade-off between internal and external validity: the more homogeneous the population, the more accurate the REE prediction but the less applicable to a heterogeneous population. Thus, future studies should be developed to test the equation within bigger samples and propose a new regression model that better adapts to the studied population.

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