8-1-2021

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Recommended Citation

Jin Xi, Carithers T, Loftin M. Prediction and Cross-validation of an Energy Expenditure Equation in Walking or Running in Asian Adults. Int J Exerc Sci. 2021 Aug 1;14(7):932-940. PMID: 34567385; PMCID: PMC8439706.

International Journal of EXERCISE SCIENCE

Original Research

Prediction and Cross-validation of an Energy Expenditure Equation in Walking or Running in Asian Adults

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ABSTRACT

International Journal of Exercise Science 14(7): 932-940, 2021. The prevalence of obesity is increasing across the world. Knowledge of the actual energy expenditure (EE) of walking and running can lead to a more precise exercise prescription which may contribute to obesity reduction or avoidance. Limited research has focused on EE prediction during walking or running in Asian adults. So, the aims of this study included developing an EE prediction equation and cross-validating the equation for Asian adults. Methods: A total of 85 Asians participated to test EE through indirect calorimetry. Linear regression analysis was employed for EE prediction, and a dependent *t*-test and Chow statistical test were used to cross-validate the equation. Results: Predicting EE during walking or running, corrected for one mile, yielded the following equation: EE = 0.933 * (Body Weight) – 4.127 * Gender (M = 1, F = 2) + 44.256 (standard error of estimate, SEE = 12.1 kcal $\cdot$mile^{-1}). A dependent *t*-test revealed no significant difference between measured EE (101.4 ± 4.3 kcal) and predicted EE (100.0 ± 2.8 kcal) ($p = 0.546$). Also, the coefficients for body weight and gender between the development prediction equation and the predicted equation in the cross-validation group were not significantly different ($p = 0.365$). Conclusion: The cross-validation results supported the validity of our predicted equation in Asians. In a practical field setting, exercise professionals could apply this equation for assessing EE during walking or running, corrected for one mile, in normal weight (body fat percentage ≤ 22 for males, ≤ 35 for females) and overweight (body fat percentage > 22 for males, > 35 for females) Asian adults.

KEY WORDS: Energy expenditure; prediction equation; walking or running; Asian; normal weight and overweight.

INTRODUCTION

The prevalence of obesity, as an international health concern, is rampant across the world. Besides dietary issues, physical activity plays a necessary role in obesity prevalence. The prevalence of low physical activity level existed around all regions of Asian (20). Additionally, in a study among 15,390 Taiwanese, half of the sample admitted that they participated in no leisure-time physical activity, and the number was even smaller among female participants (28).

In the U.S., both Asian Americans and foreign-born Asians were less likely to join in leisure-time physical activity (12), leading to the decrease of energy expenditure (EE) and then the increase of obesity. It was reported that 21.8% Asian American men were obese (19). Therefore, it is necessary to take measures to prevent and control obesity among Asians.

When designing physical activity interventions for overweight or obese adults, it is essential to know EE during exercise. Several methods for measuring EE have included direct or indirect calorimetry and doubly labeled water. These methods require sophisticated equipment and trained technicians, which are impractical in the field. Hence, some methods utilizing predictive equations with advantages of being simple, fast and low cost have been developed (23). The first predictive equation (basal metabolic rate) was developed by Harris and Benedict in 1919 (10). Several resting and exercise prediction equations followed, utilizing methods of respiratory indirect calorimetry or doubly labeled water (3, 5, 15, 16, 24, 31). However, in these equations, most researchers focus on the resting EE, equations on predicting physical activity EE is very limited. One research in sub-Sahara Africa derived an equation to predict physical activity EE (1). In this equation, EE was positively associated with accelerometry. For this reason, accelerometry was recommended to be used to predict physical activity EE. While, the cost and skill of accelerometry limited the use of this equation. So, the equation with simplicity and ease of measurement will be accepted by the public.

Additionally, the ethnic diversity of participants has been ignored by most investigators, suggesting that these predictive equations should be evaluated with caution. Most predicted equations were commonly derived from Caucasian subjects, therefore, predictions of EE in other ethnicities were not accurate (27, 29). Case, Brahler and Heiss (2), as well as Leung, Woo, Chan and Tang (15) validated the equations in Asian participants and found that most equations were not accurate with the exception of Liu's equation (16), which was developed from Chinese participants. Thus, Torun et al. (25) showed that a single equation could not predict EE for all ethnic groups, consequently, a specific equation developed for Asians is needed. The lack of consideration for ethnicity may lead to inappropriate recommendations for physical training and weight loss programs. Therefore, due to the limitation of the predicted equation on physical activity EE, especially among Asian adults, the purpose of this study was to develop and to validate a prediction equation for EE during walking or running in normal weight and overweight Asian adults.

METHODS

Participants

Eighty-five Asian participants (foreign-born Asians and Asian Americans, including 40 Chinese, 15 Taiwanese, 11 Indian, 9 Japanese, 9 Korean and 1 Singaporean), including thirty normal weight walkers (body fat percentage ≤ 22 for males, ≤ 35 for females), twenty-eight overweight walkers (body fat percentage > 22 for males, > 35 for females) (4), and twenty-seven runners, were recruited from an American University and the surrounding communities. Inclusion criteria for recruiting participants included that: 1. The participants were Asians, and their ages were between 18 and 60 years old and in good health as indicted from a health questionnaire. 2.

They were capable of understanding and providing written informed consent after a full explanation of the study. 3. They were able to walk or run on a treadmill continuously for 10 minutes. 4. Female participants were not pregnant. Exclusion criteria included that: 1. Body mass > 136 kg. 2. Resting SBP > 140 mmHg. 3. Participants were required to refrain from eating at least two hours prior to exercise tests.

The walkers and runners were all regular walkers or regular runners, which means walking or running at least 30 minutes per time and at least 3 times per week. The sample size was estimated by G*Power software (Version 3.1, Faul, 2007), in which power was set as 0.9, effect size f was set as 0.4, and error probability was 0.05 among three groups in one-way ANOVA (F test). The G*Power calculation should equal at least a sample size of 84 participants, which is close to sample size in this study (85 participants). Sample sizes in DEV group and CV group referred to the proportion of sample size in Loftin M et al. (17) and Morris CE (18). Sixty-two percent (n = 53) of the participants were in the DEV group. Thirty-eight percent (n = 32) of the participants were in the CV group, which represented 60% of the number of participants in the DEV group. Research was approved by the Institutional Review Board committee at the University of Mississippi for the use of human subjects, and each participant signed an informed consent form. Study participants have a right to privacy that should not be violated without informed consent. Experiments involving the use of human participants must follow procedures in accordance with the ethical standards of the Helsinki Declaration. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (21).

Protocol

Before EE test, each participant underwent resting baseline tests, including height, weight and dual-energy x-ray absorptiometry (DXA) for body composition (Hologic Delphi, Bedford, MA). Participants were familiarized with walking or running on the treadmill and selected their preferred walking or running speed. Preferred speeds were determined by evaluating their pace from six timed 70-foot trials on an indoor track. Participants were timed over the middle 50 feet during each trail, and preferred pace was determined as the mean pace travelled over six trials in a manner previously described (17, 18). After a brief three-minute warm-up, participants were tested by walking or running at their preferred pace on a treadmill for five minutes duration. All metabolic data, oxygen uptake, carbon dioxide production, and pulmonary ventilation, were measured using a Parvo Medics TrueOne 2400 (Sandy, UT) measurement system with accompanying mouthpiece and nose-clamp. System was calibrated against standard gases (O_2 = 16.0%, CO_2 = 4.0%). Indirect calorimetry was employed to measure EE during walking or running for five minutes at each participant's preferred pace. Average oxygen uptake during the last two minutes was used and corrected to one-mile distance (Formula: EE = VO_2 (L/min) * kcal/L O_2 * 60/speed (unit: mile/hour)). Participants were required to refrain from physical activity and ingestion of food and nutrients for at least 2 hours prior to testing in order to avoid the influence of exercise and digestion for the exercise test.

Statistical Analysis

Data was expressed as mean ± standard error (SE), and all analyses were conducted using SPSS software (Version 24, SPSS, Inc., Chicago, IL). Linear regression analysis was used to develop an equation for EE in normal weight and overweight Asians. For cross-validation, the difference between measured EE and predicted EE in the CV group was compared by using a dependent *t*-test, in which a predicted value was calculated depending on the DEV equation. Regression coefficients generated from the CV group were compared to the DEV equations' coefficients using a Chow test (proposed by econometrician Gregory Chow in 1960). An alpha level of 0.05 was set to determine statistical significance.

RESULTS

Characteristics of the participants were reported in Table 1 (mean ± SE). Figure 1 shows a scatterplot of body weight and EE to walk or to run one mile for Asians. The correlation was r = 0.800 (R^2 = 0.64). Predicting EE (kilocalories) during walking or running one mile yielded the following equation for Asians: EE = 0.933 * (Body Weight) - 4.127 * Gender (Male = 1, Female = 2) + 44.256 (SEE = 12.1 kcal $\cdot$mile^{-1}, total error = 13.0 kcal $\cdot$mile^{-1}) (DEV Equation).

Table 1. Asian Participants Basic Information

	Age (year)	Weight (kg)	Height (meter)	Fat Percentage (%)	FFM (kg)	EE (kcal)
All Asians (*n* = 85)	36.2 ± 1.2	65.9 ± 1.5	1.7 ± 0.0	26.4 ± 0.7	47.7 ± 1.2	100.2 ± 2.2
DEV (*n* = 53)	37.1 ± 1.5	65.6 ± 1.7	1.7 ± 0.0	25.8 ± 0.9	47.8 ± 1.4	99.4 ± 2.4
CV (*n* = 32)	34.8 ± 2.1	66.4 ± 2.7	1.7 ± 0.0	27.3 ± 1.1	47.5 ± 2.2	101.4 ± 4.3

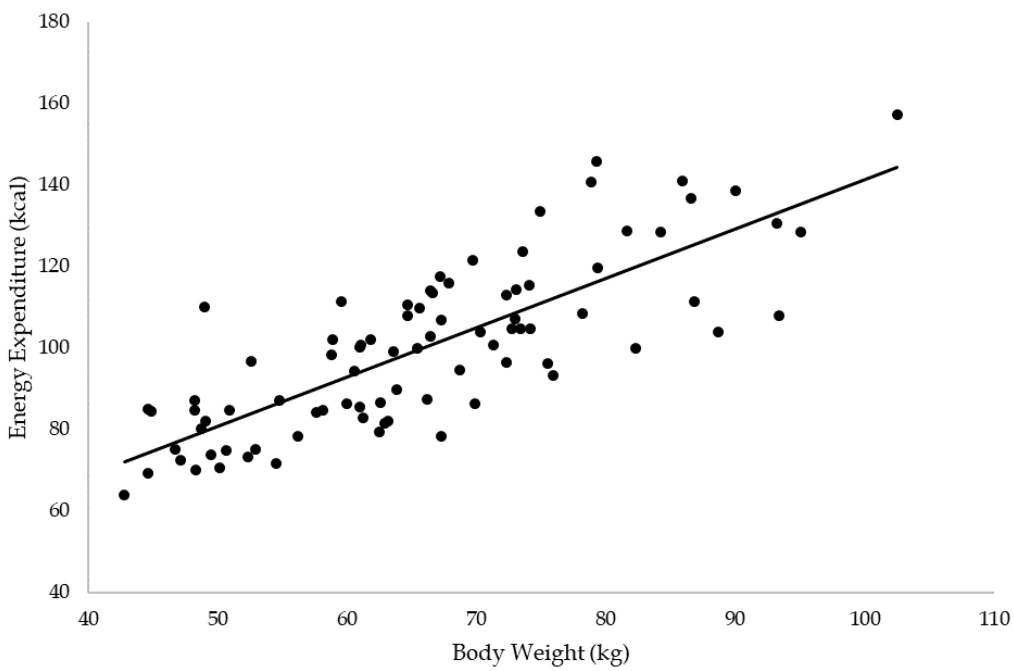

Figure 1. Scatterplot of body weight (kilograms) and energy expenditure (kilocalories) in Asians (r = 0.8).

Cross-validation

Dependent t-test: EE during walking or running one mile in the CV group was presented in Table 2. Expected EE was determined using the DEV equation. A dependent *t*-test indicated no significant difference between measured EE and predicted EE (p = 0.546).

Table 2. Energy expenditure in cross-validation group (n = 32)

Variable	Mean	SE	Min	Max
Measured (kcal ·mile^{-1})	101.4	4.3	69.4	157.4
Predicted (kcal ·mile^{-1})	100.0	2.8	77.6	135.8

Chow test: There was a strong correlation between predicted EE and measured EE in the CV group (r = 0.871, R^2 = 0.759). Through the values in the CV group, a regression equation (EE = 1.259 * (Body Weight) - 4.795 * Gender (M = 1, F = 2) + 25.039) (CV equation) was developed in order to compare coefficients to the DEV equation. The coefficient for body weight was 1.259 in the CV equation compared to 0.933 in the DEV equation. The coefficient for gender was -4.795 in CV equation compared to -4.127 in the DEV equation, and the constant was 25.039 in CV equation compared to 44.256 in the DEV equation. The Chow test was used to compare the difference of the coefficients between these two equations. There was no significant difference in the coefficients of body weight and gender (p = 0.365). Figure 2 presents the predicted EE based on body weight through the DEV equation and CV equation.

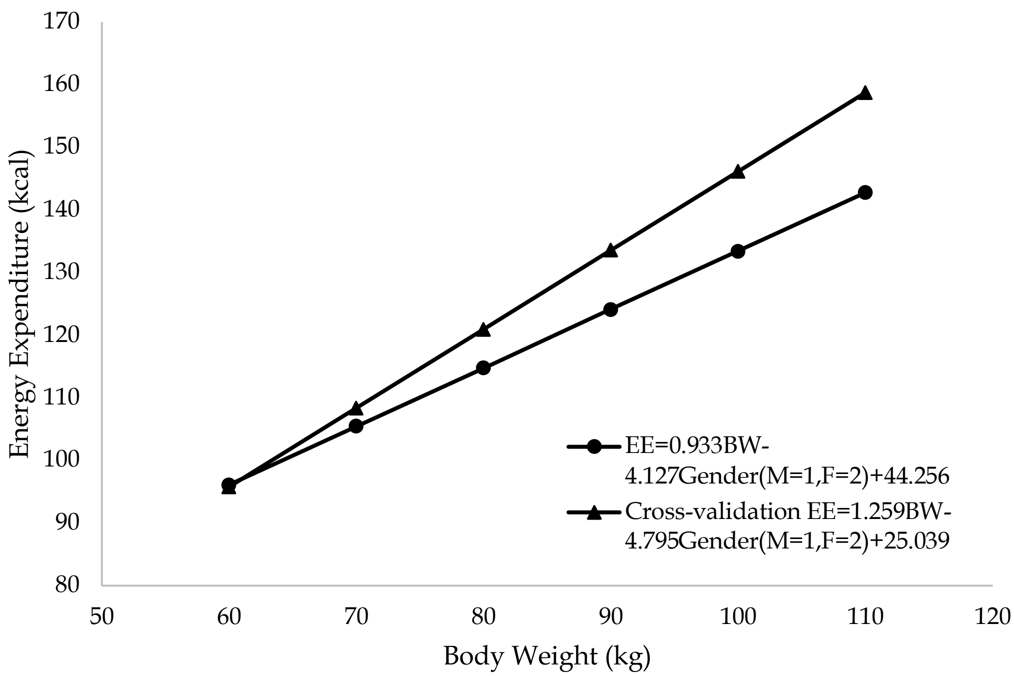

Figure 2. Predicting energy expenditure (kilocalories) based on body weight (kilograms) in Asians.

DISCUSSION

Several factors influenced EE during walking or running at a preferred pace. First, body weight had the strongest relationship with EE among all factors (R^2 = 0.64). In previous research, Heden, LeCheminant, and Smith (11) categorized body weight as normal weight and overweight, and examined the influence on EE prediction. They noted the importance of utilizing weight classifications when equations were used for assessing EE, due to an overestimation of EE in overweight women. The result of a strong relationship between body weight and EE in the current study was also supported by other researchers (6, 8, 17, 22, 26).

Preferred speed on the treadmill may be a factor that influenced the EE equation. In this between - subject designed study, speed contributed little to EE during walking or running (R^2 = 0.111) compared to the relationship between body weight and EE (R^2 = 0.640). This result aligns with previous research (7, 26), suggesting that EE may be less dependent on treadmill speed across participants of varying mass. So, body weight was considered as the most important predictor in the predicted equation. Also, if speed was set as a predictor, then subjects would need to know how fast they were moving—not always practical (treadmill walking/running works, outside walking or running works with an Apple Watch or something similar). Therefore, considering the contribution and practicality of speed, the speed of walking or running did not consider as a predictor in the equation.

Some studies show that fat mass and fat free mass (FFM) play an important role in EE prediction equations (8, 13). Wouters-Adriaens and Westerterp (31) noted that body composition, specifically a higher fat percentage found in Asians, was one reason for overestimating resting EE in Asians compared to Caucasians. In the current study, FFM accounted for a large percentage of the EE variance (R^2 = 0.627). However, in a multiple regression model, it was noted that the variance did not significantly increased after adding FFM into the overall prediction equation (ΔR^2 = 0.021). Hence, adding FFM into the equation did not add much to the predictive equation, as body weight included body composition components (fat-free mass and fat mass).

Participants' fitness levels (trained and untrained), treadmill grades and terrains (track and treadmill) were also provided as factors in the predictive equation by some researchers. However, Leger & Mercier (14) supported that it was not helpful to develop specific regression equations for trained and untrained subjects, because physically fit trained runners did not always exhibit good running economy. Also, Hall, Figueroa, Fernhall and Kanaley (9) found no significant difference of EE between track and treadmill running. Change in predicted EE was almost zero (ΔR^2 = 0.004) when adding height into the equation. Therefore, participants' fitness levels, treadmill grades, terrains, and heights were not added as a factor in the final equation developed.

In the current study, body weight and gender accounted for most percentage of EE variance (R^2 = 0.643). Moreover, there was a significant difference ($p < 0.05$) in EE between males and females. Consequently, the independent variables of body weight and gender were considered as contributors in predicting EE during walking or running one mile in Asian adults. These findings were consistent with previous studies reported by Loftin et al. (17), who developed a regression equation: kcal = mass (kg) * 0.789 - gender (men = 1 women = 2) * 7.6734 + 51.109 to predict EE for a given distance with mass and gender as predictors. It was a between-subject study with a sample size of 50 subjects, including 19 normal weight walkers, 11 overweight walkers and 20 marathon runners (17). Morris et al. (18) validated Loftin's, et al. prediction equation with 30 participants (10 normal weight walkers, 10 overweight walkers and 10 distance runners) and recommended the equation for predicting EE to run or to walk a mile.

In the CV group, no significant difference was found between measured values and predicted values, which were calculated using the DEV equation. Also, the coefficients of body weight and gender in the CV equation were compared with those in DEV equation through the Chow test. Coefficients in these two equations were not significantly different. It suggests that these two equations are not significantly different. As noted in Figure 2, the trend of regression slopes between the DEV equation and the CV equation were similar. Thus, the results of cross-validation, including dependent *t*-test and Chow test, supported the validity of the DEV equation in Asian adults.

Standard error of estimate (SEE) is used to check the accuracy of predictions in the regression line. The smaller the SEE value, the closer are the predictions to the regression line. In Loftin's EE predicted equation (17), SEE equals 10.9 kcal/mile, which is close to the SEE value of this study. According to SEE value (12.1 kcal/mile) and mean value of EE in all Asians (100.2 kcal/mile), the variation range of EE is between 88.1 kcal/mile (100.2 kcal/mile - 12.1 kcal/mile) and 112.3 kcal/mile (100.2 kcal/mile + 12.1 kcal/mile) calculated through DEV equation. In practice, the predicted EE will be within 12.1 kcal/mile variation (below or above) from the real EE value. In Table 2, results shows that the mean of predicted values is about 1% variation from the mean of test values ((101.4 - 100.0) / 101.4). Therefore, the predicted equation is acceptable based on the SEE value (12.1 kcal/mile) in this study.

There are some limitations in this study. First, all participants lived and were tested in the U.S., which limited the generalized use of this prediction equation for all Asians in other parts of the world. Many Asians maybe change their dietary habit if living in the U.S. in long term, affecting food quotient and respiratory quotient which impacts EE during physical activity (30). It will be important to include diverse Asian population in the future study. Second, the sample size in this study was eight-five. In the research of predicting equation, future study could enlarge the sample size including more Asians in different regions. Finally, the equation of this study can be used in predicting EE during walking or running one mile. Further research could explore EE equation for other types of physical activities.

In conclusion, from a practical perspective, exercise professionals could apply this equation (EE = 0.933 * (Body Weight) - 4.127 * Gender (M = 1, F = 2) + 44.256 (SEE = 12.1 kcal·$mile^{-1}$)) for assessing EE during walking or running one mile in normal weight and overweight Asian adults. Such an equation may be helpful to prevent the growing prevalence of obesity in the Asian adult population.

ACKNOWLEDGEMENTS

This research was supported by the Department of Health, Exercise Science and Recreation Management at The University of Mississippi. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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