Comparison and predicted equation of energy expenditure during walking or running among Caucasians, African Americans and Asians

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Comparison and predicted equation of energy expenditure during walking or running among Caucasians, African Americans and Asians

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A B S T R A C T

Knowledge of measured energy expenditure (EE) during walking and running is important for exercise prescription. Further, research on the EE comparison and EE predicted equation during walking or running among different ethnicities is limited. The purpose of the current study was to compare EE to walk or run 1 mile in Caucasian, African American and Asian adults and to develop a regression equation to predict EE to walk or run 1 mile. Two hundred and twenty-four participants were included (71 Caucasians, 68 African Americans and 85 Asians) with 3 groups (normal weight walking, overweight walking and running). EE was measured via indirect calorimetry. Analysis of variance was used to compare EE across groups. Multiple regression analysis was employed for EE prediction, and the prediction equation was cross-validated. A significant EE difference was found between walking and running among three ethnicities. The prediction equation was: EE = 0.978 Body Weight – 4.571 Gender (male=1; female=2) + 3.524 Ethnicities (Caucasians=1, African Americans=2, Asians=3) + 32.447 (standard error of estimate=12.5 kcal·mile^{-1}). The equation was valid through cross-validation, so it is recommended to apply for calculating EE during walking or running 1 mile among Caucasians, African Americans and Asians.

Introduction

It is reported that more than one third of the United States (U.S.) population is obese.[1] In general, physical activity is the most common way to lose weight for most individuals, and it can reduce the risks of cardiovascular disease, diabetes and some cancers, and it can enhance the quality of daily life.[2] Understanding the energy expenditure (EE) of walking or running will help exercise specialists more accurately prescribe the level of physical activity to lose weight or prevent obesity.

The comparison of EE between walking or running at a given distance has yielded mixed results. Research showed that EE during running was greater than that of walking for a given distance in the same participants (within subject design).[2–5] While, when examining participants who varied in mass (between subject design), similar EE values have been reported for walking and running.[6–9] Walking EE with adding weights on the hand and ankle leads to a higher EE cost than running EE without adding weight.[10] The increased body weight (BW), whether actual or artificial, led to the increase in EE.[8] Consequently, body weight influences EE during walking or running. Additionally, EE is different by gender. Individuals with a lower percentage of body fat carry less excess weight, resulting in less EE. Females have more fat mass and thus have to carry more extra weight than males, so their energy cost is often greater than that of males.[4,6]

EE is also influenced by ethnicity. In research comparing resting EE in African Americans and Caucasians, significantly lower values were found in the African American participants ($p = 0.04$).[11] The absolute EE was approximately 150–300 kcal lower per day in African Americans compared to Caucasians.[12] Several researchers observed that African American women had lower total daily EE than Caucasian women (about 9%), while no differences noted in males.[13–16] The lower level of physical fitness and the lower leisure time activity in African American women might have contributed to the lower value.[13] In contrast, in a study of physical activity EE, Caucasian premenopausal women had a significant higher activity-related EE (45%) than African American women.[17] In the research in Asians, their physical activity EE was lower than the U.S. counterparts.[18] Therefore, the EE difference exists among different ethnicities.

Since understanding the EE of walking or running will help exercise specialists accurately prescribe the level of physical activity, several

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List of abbreviations

ANOVA	analysis of variance
BW	body weight
DXA	dual-energy X-ray absorptiometry
EE	energy expenditure
F	female
FFM	fat free mass
FM	fat mass
kcal	kilocalorie
kg	kilogram
M	male
NWW	normal weight walking
OW	overweight walking
R	running
SE	standard error
SEE	standard error of estimate
U.S.	United States

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methods for measuring EE have been used, including indirect calorimetry and doubly labeled water. Due to the limited comparison of physical activity EE among ethnic groups, the primary purpose of this study was to compare EE differences during walking or running corrected for 1 mile among Caucasian, African American and Asian normal weight and overweight adults. Also, a purpose was to develop an equation to predict EE among Caucasians, African Americans and Asians, and to cross-validate the equation.

Method

Two hundred and twenty-four participants completed all testing (71 Caucasians, 68 African Americans and 85 Asians). Participants were divided into 3 groups: normal weight walking group (NWW) (body fat percentage ≤ 22 for males, ≤ 35 for females), overweight walking group (OW) (body fat percentage > 22 for males, > 35 for females),[19] and a running group (R). Participants were all regular walkers or runners, which means walking or running at least 30 min per time and at least 3 times per week. For regular runners, they are mostly normal weight participants. As for running group, there was no divided groups by their body weights. Inclusion criteria for recruiting participants included that: 1) The participants' 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 min. Exclusion criteria included that: 1) Body mass >136 kg. 2) Blood pressure were measured twice at rest and if 2 systolic blood pressure values were found to be above 140 mmHg or 2 diastolic blood pressure values were found to be above 90 mmHg, they would not be permitted to participate in the study. 3) Participants were pregnant.

In developing the EE prediction equation, the Caucasians, African Americans and Asians were randomly separated into 2 groups – predicted equation group and cross-validation group. One hundred and thirty-six subjects were included in the predicted group (41 Caucasians, 42 African Americans and 53 Asians), with 88 participants in the cross-validation group, (30 Caucasians, 26 African Americans and 32 Asians). Data of Caucasian participants were derived from previous published studies in our laboratory.[8,9] This research study 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.

All participants of this study were tested between 9 a.m. and 11 a.m. Before the EE test, each participant underwent resting baseline tests, including height, weight and dual-energy X-ray absorptiometry (DXA)

for testing body composition. Participants were familiarized with walking or running on the treadmill and found preferred walking speed or running speed. These preferred speeds were determined by evaluating their pace from 6 timed 70-foot trials on an indoor track. Participants were timed over the middle 50 feet during each trial, and preferred pace was determined as the mean pace travelled over 6 trials in a manner previously described.[8,9,20] After a brief 3 min warm-up, participants were tested by walking or running at their preferred paces on a treadmill for 5 min. All metabolic data, oxygen uptake, carbon dioxide production, and pulmonary ventilation, were measured using a Parvo Medics TrueOne 2400 (Sandy, UT) system accompanied with mouthpiece and nose-clamp. Before metabolic tests, system was calibrated against standard gases (O_2 = 16.0%, CO_2 = 4.0%). Indirect calorimetry was employed to measure EE during walking and running on the treadmill (0 grade), using oxygen uptake and respiratory exchange ratio, and was compared in absolute unit (kcal) and kcal relative to BW (kcal·mile^{-1}kgBW^{-1}) or fat free mass (FFM) (kcal·mile^{-1}kgFFW^{-1}). The average oxygen uptake during the last 2 min was used and corrected to 1-mile distance. Participants were required to avoid physical activity and ingestion of food and nutrients for at least 2 h prior to testing.

SPSS software (Version 24, SPSS, Inc., Chicago, IL) was employed for data analysis. ANOVA statistical analysis was used for testing main effects with post hoc Scheffe tests to compare EE across groups. Multiple regression analysis was employed for EE prediction, and a dependent *t*-test and Chow statistical test were used to cross-validate. An alpha level of 0.05 was set to determine statistical significance.

Results

Physical characteristics among Caucasians, African Americans, and Asians were presented in Table 1. As noted, a few significant differences were shown for status, mass, fat mass and fat-free mass across groups.

The EE among NWW group, OW group and R group in 3 ethnicities were shown in Table 2. In Caucasians, if EE was expressed relative to BW, the NWW group expended significantly lower EE than the R group, and if EE was relative to FFM, significant difference between the NWW group and the OW group was observed. When EE was expressed related to BW or related to FFM, the different results on EE were also noted in African Americans and in Asians. So, when the expression formats of EE were changed, the results were different among three ethnicities.

Different genders also led to different EE (Table 3). Specially, in males, both Caucasians and Asians expended significantly lower absolute EE than African Americans, while there was no significant difference between Caucasians and Asians. When EE was expressed relative to BW, there was significant difference between Caucasians and Asians. A similar result was shown if EE relative to FFM. In females, whatever the absolute EE or EE related to BW, there were significant differences

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Table 1

Physical characteristics among Caucasians, African Americans, and Asians. (standard error, *SE*; kilocalorie, kcal; body weight, BW; fat free mass, FFM).

	Caucasians		African Americans		Asians	
	Mean	*SE*	*Mean*	*SE*	*Mean*	*SE*
Age (years)	31.1[a]	1.3	21.7[b]	0.4	36.3[c]	1.2
Body weight (kg)	73.8[a]	1.7	77.1[a]	1.9	65.9[b]	1.5
Height (m)	1.72[a]	0.01	1.67[b]	0.01	1.68[b]	0.01
%Fat	23.3[a]	1.0	26.5[a]	1.2	26.4[a]	0.7
Preferred Speed (mile/h)	4.6[a]	0.2	4.4[a]	0.2	4.4[a]	0.2
Fat mass (kg)	15.9[a]	1.0	20.5[b]	1.2	17.0[a]	0.6
Fat free mass (kg)	56.0[a]	1.3	55.1[a]	1.4	47.7[b]	1.2
kcal·mile^{-1}	102.3[a]	2.0	111.3[b]	3.0	100.2[a]	2.2
kcal·mile^{-1}kgBW^{-1}	1.4[a]	0.0	1.5[a]	0.0	1.5[b]	0.0
kcal·mile^{-1}kgFFM^{-1}	1.9[a]	0.0	2.0[b]	0.0	2.1[b]	0.0

Different letters (a, b, or c) indicate significant differences ($p < 0.05$) between groups. The same letter indicates the variables are not significantly different.

Table 2

Energy expenditure among NWW, OW, and R groups in three ethnicities. (normal weight walking, NWW; overweight walking, OW; running, R; kilocalorie, kcal; body weight, BW; fat free mass, FFM).

	Caucasians			African Americans			Asians		
	NWW	OW	R	NWW	OW	R	NWW	OW	R
kcal·mile^{-1}	100.8[a]	109.3[a]	99.3[a]	98.5[a]	115.5	119.0[b]	93.8[a]	101.5[a]	115.8[a]
kcal·mile^{-1}kgBW^{-1}	1.3[a]	1.4	1.5[b]	1.4[a]	1.4[a]	1.45[a]	1.5[a]	1.4[a]	1.7[b]
kcal·mile^{-1}kgFFM^{-1}	1.8[a]	2.0[b]	1.9	1.8[a]	2.2[b]	2.1[b]	2.0[a]	2.1	2.3[b]

Different letters (a, b, or c) indicate significant differences ($p < 0.05$) between groups. The same letter or no letters indicates the variables are not significantly different.

Table 3

Energy expenditure among Caucasians, African Americans, and Asians by gender. (kilocalorie, kcal; body weight, BW; fat free mass, FFM).

	Caucasians			African Americans			Asians		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
kcal·mile^{-1}	104.2[a]	100.6[a]	102.3[a]	126.9[b]	102.2[a]	111.3[b]	112.0[a]	87.5[b]	100.2[a]
kcal·mile^{-1}kgBW^{-1}	1.38[a]	1.42[a]	1.40[a]	1.50[a]	1.42[a]	1.45[a]	1.50[a]	1.57[a]	1.53[a]
kcal·mile^{-1}kgFFM^{-1}	1.8[a]	1.9[a]	1.9[a]	1.9[a]	2.1[a]	2.0[a]	2.0[a]	2.3[b]	2.1[a]

Different letters (a, b, or c) indicate significant differences ($p < 0.05$) between groups. The same letter indicates the variables are not significantly different.

between Caucasians and Asians, and between African Americans and Asians. When EE was expressed related to FFM, significant differences were shown among 3 ethnicities.

In a regression equation, predicting EE (kcal) during walking or running 1 mile yielded the following equation: EE = 0.978 BW – 4.571 Gender (male, M = 1; female, F = 2) + 3.524 Ethnicities (Caucasians = 1, African Americans = 2, Asians = 3) + 32.447 (SEE = 12.5 kcal·mile^{-1}). The scatterplots of BW and EE to walk or to run 1 mile in each ethnicity and in 3 ethnicities were shown in Fig. 1. It suggests the strong correlation between BW and EE.

EE during walking or running 1 mile in the cross-validation group of Caucasians, African Americans and Asians was presented in Table 4. The average EE was 106.9 ± 2.5 kcal·mile^{-1}, and the mean predicted EE was 103.6 ± 1.7 kcal·mile^{-1}. A dependent t-test showed that the predicted equation significantly underestimated the EE during walking or running 1 mile in the cross-validation group ($p < 0.05$). However, the difference of EE (106.9–103.6 = 3.3 kcal·mile^{-1}) was within the standard error of estimate (SEE = 12.5 kcal·mile^{-1}) of the predicted equation. Further, a

Table 4

Energy expenditure during walking or running 1 mile in 3 ethnicities' cross-validation group (kilocalorie, kcal; standard error, SE).

Variable	Mean	SE	Min	Max
Measured kcal·mile^{-1}	106.9[a]	2.5	53.9	183.8
Predicted kcal·mile^{-1}	103.6[b]	1.7	74.2	138.7

Different letters (a, b, or c) indicate significant differences ($p < 0.05$) between groups. The same letter or no letters indicates the variables are not significantly different.

strong correlation between predicted EE and measured EE in the cross-validation group was found (r = 0.822, R^2 = 0.676). A regression equation [EE = 1.143 BW – 5.931 Gender (M = 1, F = 2) + 2.34 Ethnicity (Caucasians = 1, African Americans = 2, Asians = 3) + 28.195] was generated using data from the cross-validation group in order to compare coefficients with the predicted equation above. Coefficients and constants in the cross-validation group, compared with that in the predicted
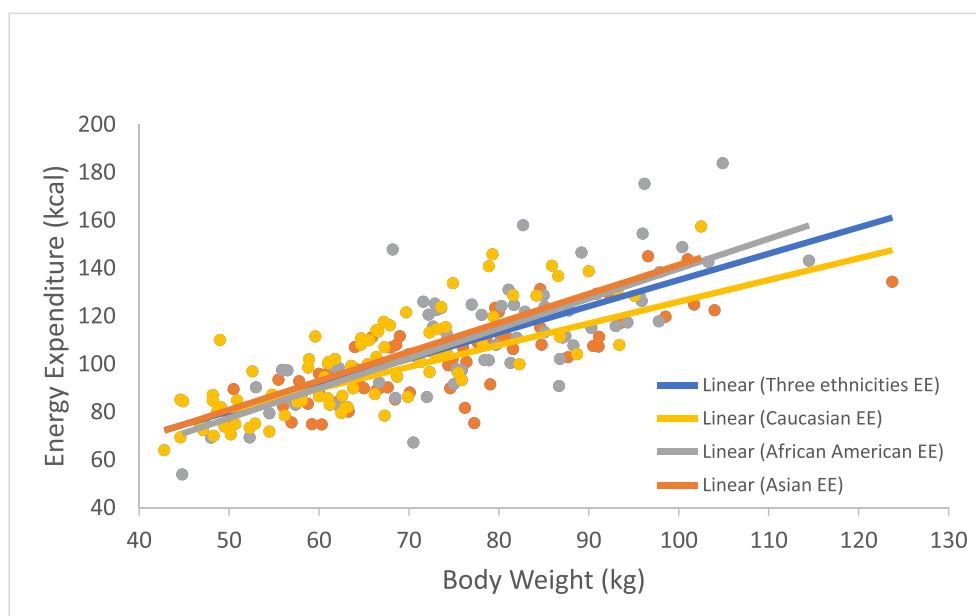
Fig. 1. Scatterplot of body weight (kilogram, kg) and energy expenditure (energy expenditure, EE; kilocalorie, kcal) to walk or run 1 mile in Caucasians, African Americans, Asians and in 3 ethnicities.

equation through the Chow test, indicated that there was no significant difference in the coefficients of body weight, gender and ethnicity ($p = 0.589$). In Fig. 2, similar trends are noted between the predicted equation and cross-validated equation.

Discussion

Body composition and EE

In this study, results showed that body mass in Asians was significantly lower than that of Caucasians and African Americans. In recent similar work, Loftin et al.[8] observed that mass accounted for about 59% of the EE variance in predicting walking or running EE. Additionally, African Americans had the greatest fat mass (FM) in three ethnicities. Asians exhibited the lowest value of FFM among 3 ethnic groups. The result in our study echoed 1 study in which FFM of Asians was significantly lower than that of Caucasians,[21] and this result also confirmed that there was no difference of FFM between African Americans and Caucasians.[22] However, limited research has been conducted on comparing FFM in Caucasians and African-Americans.[16,23] Therefore, determining the methods for calculating an accurate body composition is necessary. To avoid overestimating FFM, some researchers specified FFM into limb lean mass and truck lean mass. It was demonstrated that African Americans had higher limb lean tissue and lower truck lean tissue than Caucasians, even though they had similar FFM totally.[24] Thus, measures of FFM by body parts may be necessary before comparing physical characteristics, which may lead to the differences of EE.

Examination of EE by walking and running

In African Americans, the NWW group expended less absolute EE than the R group. Because walking limb posture was more upright than running, muscles generated lower force in walking, which cost less EE.[25] In the present study, as expected, the OW group had significantly higher body weight than the R group. The greater the body mass, the greater the energy cost. Thus, a strong relationship between BW and EE was found in this study ($r = 0.775$). When EE was expressed relative to FFM, EE in the NWW group was lower than that in the R group and in the OW group. It has been reported that the higher FFM contribute to the higher basal metabolic rate, which may lead to the increase of total EE.[26]

The majority of previous research exploring EE have focused on the resting EE, while physical activity EE contributes to weight loss most. The result of this study was consistent with 1 study, in which African Americans expended more energy than Caucasians.[27] Caucasian participants in the current study were significantly taller than that of African American and Asian participants. During walking or running, this might lead to a greater vertical movement and longer stride with decreased stride frequency.[4,5] In a recent review, Ceaser and Hunter[28] noted that African Americans had reduced hemoglobin concentration compared to Caucasians. During exercise, hemoglobin was important in oxygen transportation from respiratory organs to working muscles. Furthermore, African Americans had more type II muscle fibers, which resulted in the reduced endurance and increased fatigue. The reduced hemoglobin concentration and more type II muscle fibers might have influenced the lower aerobic capacity in African Americans.[28] All these factors perhaps contributes to the difference of exercise or physical activity EE in African Americans.

Predicting and cross-validating EE equation

When planning physical activity interventions of weight management for overweight or obese adults, it is essential to know the EE during exercise. It would be convenient for clinicians to predict EE in exercise prescription just based on some convenient obtained variables, such as body weight or gender. In the current study, several factors influenced EE during physical activity. BW had the strongest relationship with EE

among all factors ($r = 0.775$). Researchers categorized BW as normal weight and overweight, and examined the influence on EE prediction. It was noted that the importance of weight classification was highlighted for the accuracy of EE when equations were used for assessing EE.[29] Loftin et al. emphasized the importance of mass and reported that mass accounted for about 59% of EE variance.[8] So, BW was thought as an important predictor in EE prediction equation. In the EE prediction equation, BW and gender together accounted for the most variance in prediction equation with gender adding another 1.6% of EE variance ($R^2 = 0.616$). After adding the factor of ethnicity, the relationship between predictors and EE increased ($R^2 = 0.628$). Therefore, ethnicity accounted for 1.2% for equation ($\Delta R^2 = 0.012$). It is suggested that ethnicity plays some roles in developing equation among different populations.

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 ($r = 0.183$, $R^2 = 0.03$) compared to the relationship between body weight and EE ($r = 0.775$, $R^2 = 0.60$). This result aligns with previous research,[30,31] 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, which is 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 was not considered as a predictor in the equation.

In cross-validation of predicted equation, a significant difference between measured and predicted values in cross-validated group was noted in this study. However, EE difference ($106.9–103.6 = 3.3$ kcal·mile^{-1}) was within the *SEE* (12.5 kcal·mile^{-1}). In the Chow test, the result indicated that there was no significant difference between coefficients in these 2 equations ($p = 0.589$). Therefore, the cross-validation supported the validity of predicted equation. The EE predicted equation [EE = 0.978 BW – 4.571 Gender (M = 1, F = 2) + 3.524 ethnicities (Caucasians = 1, African Americans = 2, Asians = 3) + 32.447 (SEE = 12.5 kcal·mile^{-1})] would be useful for physical training and weight management during walking or running 1 mile among Caucasians, African Americans and Asians in the future clinical practice.

Strengths and limitations

To our knowledge, this is the first EE predicted equation of walking or running one mile for Caucasians, African Americans, and Asians. This equation could be valid to predict EE, so it can be used as a tool in public health to help avoid or control obesity. However, there are some limitations in this study. First, in research predicting EE during walking or running, the sample size could be larger. Therefore, we suggest future research with an increased sample size that may yield a more generalization of EE equation from the current work. Also, the participants of this study included females, and the women's menstrual cycles should be considered. In addition, the exercise types were focused on walking and running in this study. Further studies could explore other exercise types, such as swimming, to predict EE in other exercise fields. Last, the EE predicted equation developed in this study can be used in Caucasians, African Americans, and Asians. The EE predicted equation will be extended in other ethnicities for widely use.

In summary, physical activity EE was affected by energy expression format, which were absolute energy, EE relative to BW, and EE relative to FFM. The types of exercise (walking or running within subjects) and different genders influenced physical activity EE. Also, ethnicities played an important role in EE during walking or running. In this study, the predicted EE equation was developed for Caucasians, African Americans, and Asians [EE = 0.978 BW – 4.571 Gender (M = 1, F = 2) + 3.524 ethnicities (Caucasians = 1, African Americans = 2, Asians = 3) + 32.447 (SEE = 12.5 kcal·mile^{-1})]. Cross-validation testing supported the validity of the predicted equation. Therefore, we recommend to use the equation
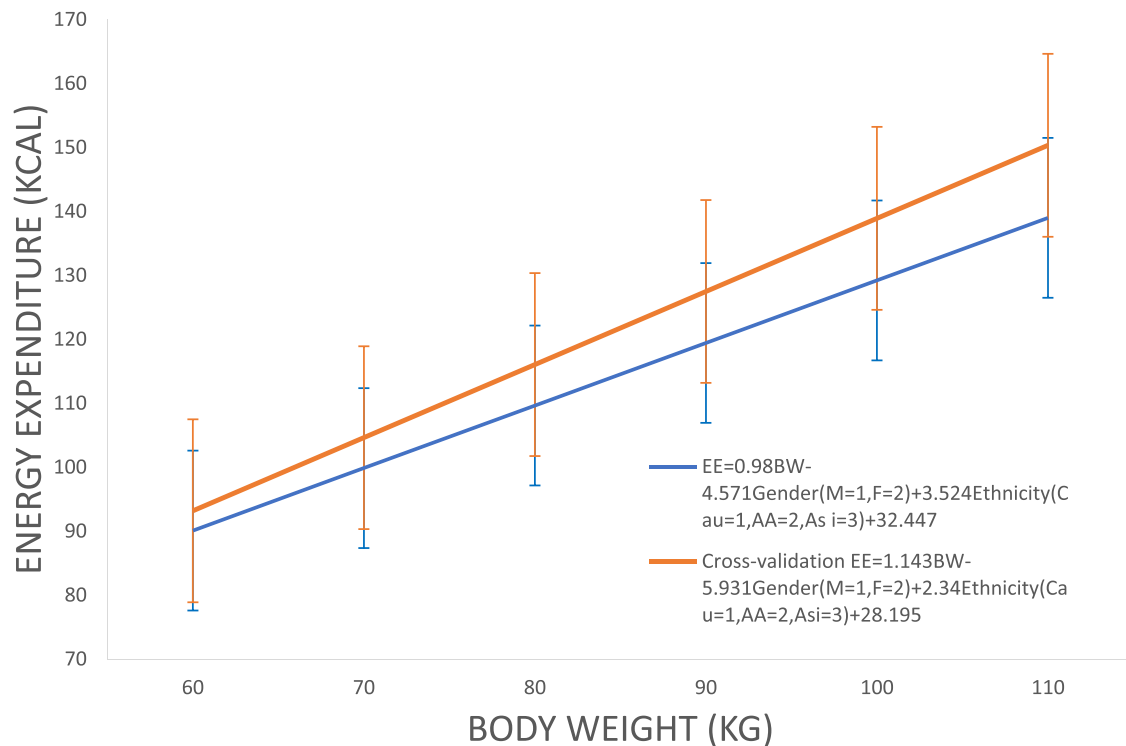
Fig. 2. Predicting energy expenditure (energy expenditure, EE; kilocalorie, kcal) based on body weight (kilogram, kg) in Caucasians (Cau), African Americans (AA) and Asians (Asi) (male, M; female, F).

to predict EE during walking or running 1 mile for normal weight and overweight adults among African Americans, Asians, and Caucasians.

Ethical approval statement

This research study was approved by the Institutional Review Board committee at the University of Mississippi (16-051) for the use of human subjects, and signed informed consent was obtained from each participant.

Submission Statement

Authors confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. Its publication is approved by all authors.

Authors' contribution

Xi Jin and Mark Loftin conceived and designed research. XJ was responsible for writing the protocol and report, conducting experiments, extracting and analyzed data, interpreting results, updating reference lists and creating 'Summary of findings' tables with the guidance of ML. All authors, including Xi Jin, Mark Loftin and Teresa Carithers read and provided feedback on the report.

Conflict of interest

The authors declare no competing financial interest.

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