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A Comparison Of Energy Expenditure And Prediction Equations During Walking Or Running Corrected For One Mile In Normal Weight And Overweight African American, Asian, And Caucasian Adults And Cross-Validation Of The Equations

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A COMPARISON OF ENERGY EXPENDITURE AND PREDICTION EQUATIONS DURING WALKING OR RUNNING CORRECTED FOR ONE MILE IN NORMAL WEIGHT AND OVERWEIGHT AFRICAN AMERICAN, ASIAN, AND CAUCASIAN ADULTS AND CROSS-VALIDATION OF THE EQUATIONS

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ABSTRACT

The prevalence of obesity is rapid across the world. Knowledge of the actual energy expenditure (EE) of walking and running can lead to a more precise exercise prescription which may lead to an obesity reduction or avoidance. Limited research has focused on EE during walking and running. Therefore, the aims of this study included developing ethnic based cross validated EE prediction equations for African American, Asian and Caucasian adults, and a multiple regression equation developed that included all three ethnic groups. Also, the energy expenditure among these three ethnic groups were compared. A total of 224 subjects, including 71 Caucasians, 68 African Americans and 85 Asians were recruited to test EE through indirect calorimetry. Analysis of variance (ANOVA) was used for overall significance with post hoc Scheffe test to compare EE in three groups (normal weight walkers, overweight walkers and runners). Multiple regression analysis was employed for EE prediction, and a dependent t-test and Chow statistical test were used to cross-validate. The results showed that EE in runners was significantly higher than that in normal weight walkers in African Americans. When EE was expressed relative to body weight, similar difference was observed between walkers and runners in both African Americans and Asians. When EE was expressed relative to fat free mass, normal weight walkers expended less energy than runners, both among African Americans and Asians. Furthermore, EE in African Americans was significantly higher than that in Caucasians and in Asians. Three EE prediction equations were developed specifically for African Americans, Asians, and the three ethnic groups. Through cross-validation, all the three equations were valid and they were all recommended to apply for calculating EE during walking or running one mile. The overall prediction equation was: EE=0.978 BW-4.571 Gender (M=1, F=2)+3.524 Ethnicity (Caucasians=1, AA=2, Asians=3)+32.447 (R=0.77; SEE=12.5 kcal·mile^{-1}).

DEDICATION

I dedicate this dissertation to my parents who give me a great support. It is their unconditional love that motivates me pursue progress. I also dedicate this dissertation to Dr. Mark Loftin who guides and builds my goal towards the world of exercise science.

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CHAPTER 1

INTRODUCTION

It is reported that more than one third of the U.S. population is obese (Flegal et al., 2010), and it is predicted that 40% of men and 43% of women will be obese by 2020 (Ruhm, 2007). In African-American women, the prevalence of overweight or obesity is 1.4 times greater than that of Caucasian women (Weinsier et al., 2000). Obesity is classified as a disease and is also a leading comorbidity for other diseases, such as hypertension and cardiovascular diseases (CVD). Obesity also adds more economic burden on the government and society. In 1990, obesity- related cost was about $45.8 billion, accounting for approximately 6.8% of all health care expenditures in the United States (Quesenberry et al., 1998), and it increased to approximately $99.2 billion in 1995 (Wolf and Colditz, 1998). Meanwhile, about 44 million people tried to lose weight through eating low-calorie diet and increasing physical activity, which are thought to be the best strategies to lose weight (Horm and Anderson, 1993), because low physical activity may be a cause of weight gain and thus can enhance obesity status (Weinsier et al., 2000). About five million U.S. adults used pills to lose weight (Khan et al., 2001).

Research has shown that African Americans participated in less physical activities than Caucasian Americans, especially women (DiPietro and Caspersen, 1991; Pate et al., 1995; Washburn et al., 1992). DiPietro and Caspersen (1991) noted that 29.3% of African-American males were physically inactive with 8.2% considered meeting appropriate physical active guidelines. These percentages contrasted with Caucasian males (physically inactive 24.5%, physically active 8.7%). In African-American women, 33.4% were considered physically inactive, with 6.1% being physically active. Finally, the percentage of Caucasian women physically inactive was 29.7%, with 7.6% appropriately meeting physical activity guidelines. Interestingly, African-American men and women spent more time walking per day than Caucasian men and women (12.2 min/ day vs. 9.2 min/ day) (DiPietro and Caspersen, 1991). Washburn et al. (1992) surveyed a random sample of South Carolina residents (1984 and 1985) for sedentary leisure time physical activity (completed sedentary at leisure). The investigators found 32% and 36% for African-American men and women, respectively, were completely sedentary, while 26.9% and 30% of Caucasian men and women, respectively, were considered completely sedentary at leisure. Moreover, African Americans (301kcal/ week) were significantly less active ($p \leq 0.01$) for median levels of leisure time energy expenditure than Caucasians (601kcal/ week) (Washburn et al., 1992).

Comparing the specific physical activity, African Americans had the lowest percentage of leisure-time physical activity, and Asians had the lowest percentage of household-related activities (Dong et al., 2004). Further, Müller et al. (2013) in a review paper reported the low level of physical activity in Asian school age children and adolescents. The urban Asian population spent more time watching television, which is significantly associated with high blood pressure, cholesterol and other cardiovascular and metabolic disease risk factors (Nang et al., 2013). In a survey of 15,390 Taiwanese, half of the subjects admitted to having no leisure-time physical activities, and women were lower than half (Wai et al., 2008). Meanwhile, females were more inactive compared to males in South Asia. Due to the lower proportion of female walkers, they were more like to be obese compared to European women. Also, over 80% difference of BMI between South Asians and Europeans was explained by lower physical activity level outside the workplace.

Females also had higher prevalence of overweight and obesity in Indians (Chopra et al., 2013; Pomerleau et al., 1999; Ranasinghe et al., 2013). Even though Asian Americans were much less likely to join in leisure-time physical activity, foreign-born Asians were least likely, which lead to lower energy expenditure (Kandula and Lauderdale, 2005). These results support the higher percentage of obesity levels in African Americans and in Asians compared to Caucasians, in particular, African-American women and Asian women. Obesity has become a worldwide issue, and, therefore, it is very urgent for us to find some effective ways to tackle this problem.

Many efforts have been taken to control body weight. In general, physical activity is the most common way most people choose, which can reduce the risk of CVD, diabetes, some cancers, and enhance the quality of daily life (Wilkin et al., 2012). In 2007, the updated recommendation from the American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommended that all healthy adults participate in moderate intensity aerobic physical activity for a minimum of 30 minutes per day for at least 5 days per week or vigorous intensity aerobic activity for a minimum of 20 minutes per day at least 3 days each week. Additionally, muscular strength and endurance activities were suggested for a minimum of 2 days each week (Haskell et al., 2007). When choosing walking as a physical activity, adults should expend at least 1000 kcal per week to maintain health (ACSM, 2010). However, Haskell (2007) reported that only 41.8% of African Americans and 51.1% of Caucasians met the 2010 recommendation.

In exercise intervention programs, aerobic endurance training is typically the preferred exercise regimen to reduce weight. Meanwhile, walking or running has many benefits, such as being highly accessible, easily adopted, and causing less injury (Hu et al., 1999). Leon, et al. (1979) reported that body weight decreased due to decline in body fat with a little gain in lean tissue after vigorous walking, without controlling diet. When exercise professionals provide a weight loss program for obese people, it is preferred to assess the energy expenditure during exercise prescription. Currently, a variety of methods have been used to measure energy expenditure, including direct measurement, self-reported questionnaires, doubly labeled water, and some simple and convenient devices, such as pedometers. Advantages and limitations exist for each of these assessment methods of energy expenditure. Taking the method of doubly labeled water as an example, it is considered a gold standard in measuring energy expenditure because of the high degree of validity. But it is expensive and could be used only in clinical and laboratory settings, rather than during exercise. Thus, in clinical application of weight management for normal weight and overweight individuals, it will be convenient for clinicians to predict energy expenditure with easily collected variables, such as body weight or gender, avoiding the sophisticated equipment and training needed.

Understanding the energy expenditure of walking or running will help exercise specialists more accurately prescribe the level of physical activity in order to lose weight or to prevent obesity. However, the results of comparison on energy expenditures between walking and running are inconsistent. Also the result of comparison is different by gender, mostly attributing to fat-free mass differences. Most research was on the comparison of resting energy expenditure (REE) in African Americans and Asians with limited data on physical activity energy expenditure (PAEE), which is more important than resting energy cost. PAEE can compensate for the lower REE because there is less change in REE by participants themselves. For PAEE, most researchers paid attention to self-reported physical activity through questionnaires, which could easily overestimate the physical activity level. Only a few articles on PAEE were tested by exercise, such as cycling and stepping exercises, without walking or running, especially without the comparison in energy expenditure between them. Therefore, assessing the walking and running energy expenditure in African Americans and Asians, and the comparison of energy expenditure between walking and running among Caucasians, African Americans, and Asians may play an important role in controlling the prevalence of obesity.

CHAPTER 2

LITERATURE REVIEW

In regard to physical activities or exercise that Americans enjoy, Stephens et al. (1985) noted that walking was the most common physical activity and running is also one of the top six physical activities (Stephens et al., 1985). Knowledge of the actual energy expenditure of walking and running is important for prescribing exercise to avoid excess body mass and/ or to maintain appropriate body mass. The energy expenditure comparison between walking or running a given distance has yielded mixed results. Bhambhani and Singh (1985), Hall et al. (2004), Howley and Glover (1974), and Wilkin et al. (2012) reported that the energy expenditure during running was greater than that of walking for a given distance in participants that both walked and ran a given distance (with-in subject design). On the other hand, when examining participants who varied in mass (between subject design), similar energy expenditure values have been reported (Browning et al., 2006; Kram and Taylor, 1990; Loftin et al., 2010; Morris et al., 2014).

Kram and Taylor (1990) compared the energy cost of running at a slow or a fast speed with quadrupeds that varied in mass from 32 g to 141 kg. The investigators noted that energy expenditure of running at either a slower or a faster speed did not significantly alter the energy cost (Kram and Taylor, 1990). Loftin et al. (2010) reported similar energy expenditure values during walking and running in normal weight walkers (NWW), overweight walkers (OW) and in marathon runners (MR) when energy expenditure was expressed as absolute energy expenditure (kcal/mile). When energy expenditure was expressed relative to mass (kcal/kg body mass), significant differences were indicated, with the highest values found in the marathon runner group followed by normal weight walker group and overweight group.

However, when energy expenditure was expressed per kg of fat free mass, no differences were identified across groups. Because of the similar fat-free mass across groups, the excess mass was primarily adipose tissue. Miller and Stamford (1987) demonstrated that walking energy expenditure with added hands' and ankles' weights cost more than running without adding weight. The increase of body weight, whether actual or artificially, led to the increase in energy expenditure increasing (Loftin et al., 2010).

Welle et al. (1992) compared the basal metabolic rate (BMR) and free-living energy expenditures in overweight and normal weight women. BMR was determined by indirect calorimetry and free living energy expenditure by the $H_2^{18}O$ method (deuterium oxide). Due to the excess body mass, primarily the fat mass, the overweight groups BMR and free-living energy expenditure (MJ/day) were significantly higher than those values found in the normal weight group. The significant difference disappeared after BMR and free-living conditions were adjusted for body mass or lean body mass. Welle et al. (1992) concluded that the overweight women in their study, due to excess the fat mass, must exhibit a higher BMR value to maintain their excess weight. Similar results were noted by Treuth et al. (1998), whose study included overweight and non-overweight prepubertal girls.

Browning et al. (2006) indicated that it was not the body mass distribution, but the percentage of body fat that explained differences in net metabolic rate, which accounted for about 45% of variance in the net metabolic cost of walking. Öhrström et al. (2001) examined the energy expenditures of eleven obese women following vertical banded gastroplasty (VBG) surgery. They found that after VBG induced weight loss, the energy expenditure (absolute units) during walking was reduced at comfortable and preset walking speeds. However, when energy expenditure was expressed per kg of mass, it was increased at comfortable walking speed, which could be explained by increased walking speed. The authors postulated that the decreased energy expenditure mainly resulted from less need for energy to move the body with smaller body mass following VBG, decreased working capacity related to cardiorespiratory function, thermic effect of feeding, and ease of overcoming the inertia or friction.

Energy expenditure differences by gender

Individuals with a lower percentage of body fat carry less excess weight, resulting in expending less energy expenditure. Also, the percentage of body fat typically explains about 45% of the variance in net metabolic rate. As a result, females have more fat mass and thus have to carry more extra weight than males, so their energy cost is greater than that of males (Browning et al., 2006; Hall et al., 2004). Additionally, the greater energy cost of walking and running in women often varies with values in males with respect to how energy expenditure was expressed. When energy expenditure was expressed per kg of body weight per mile, differences were noted; however, gender related energy expenditure differences disappeared when expressed by body surface area (i.e., kcal/ m^2 per mile) (Bhambhani and Singh, 1985; Howley and Glover, 1974). Loftin et al. (2010), Morris et al. (2014), and Hall et al. (2004) showed that gender differences disappeared when energy expenditure was expressed relative to mass or fat-free body mass during walking or running. However, Hall et al. (2004) observed a greater energy expenditure in males greater than in females, which was perhaps due to the significantly larger metabolically active tissue (fat-free mass) in males. They suggested that the lower fat-free mass in females attributes to why women face a greater difficulty than men to lose weight in walking or running programs (Hall et al., 2004).

Females tend to expend less absolute calories (kcal) energy than males during walking or running. However, research by Howley and Glover (1974) found that energy expenditure relative to body weight (kcal/kg) during running in males was lower than in females perhaps due to a greater stride frequency, and due to a greater vertical displacement in women at a slower speed of running as a result of longer stride length. These factors perhaps increased the total amount of work and energy cost in females (Howley and Glover, 1974). However, Bhambhani and Singh (1985) observed through cinematography no gender differences in the vertical lift per stride length. Although males lift work was 11-12% less than females, the investigators thought that the reduced lift work with shorter strides was needed to increase stride frequency, which involved more muscle work and resulted in more energy needed (Falls and Humphrey, 1976).

Additionally, Bhambhani and Singh (1985) suggested that the oxygen recovery was another factor to explain gender differences in energy expenditure. The investigators observed that the oxygen recovery in females accounted for about 20.1% of the total oxygen cost, compared to 17.3% in males. Although fat-free mass appears to be a primary determinant of gender differences, age and training status may also account for gender difference (Miller and Stamford, 1987; Wilkin et al., 2012).

Resting energy expenditure and physical activity energy expenditure

In research comparing the resting energy expenditure (REE) in African American and Caucasians, significantly lower values were found in the African American participants ($p = 0.04$), even after adjustment for body weight ($p = 0.02$) and for fat-free mass ($p < 0.0001$) (Foster et al., 1997). Moreover, several investigators have noted energy expenditure differences of approximately 150-300 kilocalories lower per day in African Americans when compared to Caucasians (Amen-Ra et al., 2012; Kaplan et al., 1996; Sun et al., 2001). When analyzing the reasons of lower REE in African Americans, most studies first paid attention to the overall fat-free mass between African Americans and Caucasians, and fat-free mass and ethnic background were identified as the most important combination of predictors of REE ($R^2 = 0.70$) through regression analysis (Tershakovec et al., 2002).

In other research, African Americans had lower fat-free mass than Caucasians (Amen-Ra et al., 2012; Kaplan et al., 1996) and in South Africans (Dugas et al., 2009), whereas the opposite result was found by other investigators (Foster et al., 1997; Weyer et al., 1999). Specifically, African American children and women had higher limb lean mass than Caucasians, which was the main component of total lean mass and the sum of skeletal muscle in arms and legs. But African Americans also had lower trunk lean mass, which was the organ component, a similar amount of total fat-free mass. These two results led to the higher proportion of muscle and the lower proportion of metabolically active organ tissue that composed most REE (Foster et al., 1997). And when fat-free mass composition is specific high-metabolic-rate organs, which are liver, heart, spleen, kidneys and brain, their mass is significantly smaller in African Americans than in Caucasians after adjustment for fat, fat-free mass, sex and age ($p < 0.001$), which explained more than half of the REE difference between African Americans and Caucasians (Gallagher et al., 2006). In addition, the respiratory quotient (RQ) was also taken into account as another reason of lower REE in African Americans. Weyer et al. (1999) found that the 24-hour RQ in African Americans was higher than that in Caucasians (males and females). These results suggest that the African Americans who had lower fat oxidation (a high RQ) may gain weight more easily. Also, African American males had a lower rate of fat oxidation and a higher rate of carbohydrate oxidation, but females did not (Weyer et al., 1999). However, the higher respiratory exchange ratio (RER) in African American women also means the lower oxidation of fat, and they prefer carbohydrate utilization, which is a high risk factor of body weight gain (Chitwood et al., 1996).

From the review studies above, some researchers have noticed that the REE in African Americans was lower than that in Caucasians. Also, the deficit in REE among African Americans should be compensated by the increase of physical activity in order to control the high rate of obesity. In a recent study, Amen-Ra et al. (2012) reported that African Americans had significantly higher voluntary energy expenditure than Caucasians ($p < 0.05$), as indicated by accelerometry. Also, males exhibited higher levels of physical activity than females ($p < 0.001$), which was still significant after adjustment for body fat content. And African Americans were engaged in more physical activity than Caucasians.

Several researchers have observed that African American women had lower total daily energy expenditure (TDEE) than Caucasian women (about 9%), with no differences noted in males (Dugas et al., 2009; Lovejoy et al., 2001; Weinsier et al., 2000; Weyer et al., 1999). However, Weyer et al. (1999) reported similar TDEE in African American and Caucasian participants. Perhaps a lower TDEE can be accounted for by PAEE. African American women required about 6% lower exercise energy cost than that of Caucasian women (Weinsier et al., 2000), and 25% lower was found by Dugas et al. (2009). In this study, exercise included two parts: stationary cycle ergometer exercise with light intensity (three METs) and moderate intensity (six METs) workloads, and weight bearing stepping exercise with light intensity (four METs). Dugas et al. (2009) suggested that the lower level of physical fitness (self-reported) in African American women may have attributed to the lower PAEE.

Lovejoy et al. (2001) reported significantly lower leisure time activity in African Americans than Caucasians ($p = 0.02$), with fewer hours spent standing and fewer flights of stairs climbed in the African Americans. In two studies of older free-living African Americans, it was noted that TDEE, RMR and PAEE were lower than values observed in Caucasians, and also lower in women and in men after adjustment for FFM, mainly due to the PAEE. PAEE is quantitatively more important than resting metabolic rate (RMR) to explain the gender differences, in which PAEE is more than RMR, and the greater body fat and increased cardiovascular risk in women contribute to lower PAEE (Carpenter et al., 1998; Starling et al., 1998). Meanwhile, in one relatively large sample study, the PAEE was most pronounced in women, 37% lower than in men, compared to RMR (6%). The strongest correlation with PAEE for women was with age ($r =-0.44$; $p < 0.01$), and for men, it was VO_2max ($r = 0.39$; $p < 0.05$), attributing to the greater loss of skeletal muscle mass and cardiorespiratory fitness with aging, respectively (Starling et al., 1998). Similarly, Kushner et al. (1995) reported that the PAEE in African Americans women was significantly lower than that in Caucasian women, measured by the equation (PAEE= TDEE- basal metabolic rate- thermic effect of a meal), which was the lack of objective physical activity measurement, although no difference was observed in TDEE. Oppositely, one study found PAEE in African Americans higher than Caucasians, with the same result in African Americans and Caucasian men, but no difference in women (Weyer et al., 1999). The contradictory results may be attributed to the experimental design in exercise, participants' fitness level and age, and sample sizes of studies.

Limited research on walking or running energy expenditure is available. In only one study of level walking (0% grade, 3 mph, 4 min) and grade walking (2.5% grade, 3 mph, 4 min), Hunter et al. (2004) indicated that Caucasian premenopausal women had a significant higher activity-related energy expenditure (45%) and activity-related time equivalent index (50%), which was an index of time spend in physical activity, than African American women. However, limited research has been completed examining energy expenditure differences in African American and Caucasian adults.

Prediction equation for energy expenditure

When designing physical activity interventions of weight management for overweight or obese adults, it is essential to know the energy expenditure during exercise. Also, it will be convenient for clinicians to predict energy expenditure in exercise prescription just based on some easily obtained variables, such as body weight or gender. So several methods for measuring energy expenditure included indirect calorimetry, direct calorimetry, doubly labeled water and predictive equations. Among these methods, even though many were considered as gold standard methods, such as direct calorimetry, respiratory indirect calorimetry and doubly labeled water, they were impracticable in the field or required sophisticated equipment or trained persons. Thus, the method of predictive equations with the advantage of simple, fast and low cost was developed by some researchers (Pinheiro Volp et al., 2011). The first predictive equation was published in 1919 by Harris and Benedict (Harris and Benedict, 1919). Then, several equations were derived by other authors through the methods of respiratory indirect calorimetry or doubly labeled water (Case et al., 1997; Compher et al., 2004; Daly et al., 1985; Leung et al., 2000; Liu et al., 1995; Mifflin et al., 1990; Spears et al., 2009; Wouters-Adriaens and Westerterp, 2008). Many of the energy expenditure prediction equations were focused on REE, and less were focused on energy expenditure of physical activity. However, these predictive equations should be evaluated with caution, because ethnicity diversity of subjects was ignored by most investigators. Because predicting equations were commonly derived from Caucasian subjects, the data on REE prediction in other ethnicities were not accurate (Vander Weg et al., 2004; Weijs, 2008). Some equations were overestimated (Daly et al., 1985; Mifflin et al., 1990; Spears et al., 2009; Wouters-Adriaens and Westerterp, 2008), and others were underestimated (Spears et al., 2009). In the study of 502 Caucasian and African American girls and boys aged 6-11 years, McDuffie et al. (2004) showed that previously developed prediction equations were not accurate for REE in African American children. Also, Case et al. (1997) and Leung et al. (2000) validated the equations in Asian subjects and found that most equations were not accurate except the Liu's equation (Liu et al., 1995), which was developed from Chinese participants. Liu et al. (1995) reported that the current predictive equations for basal metabolic rate were overestimated for healthy Chinese adults. Some experts also suggested that only a single equation could not predict energy expenditure for all ethnic groups (Torun et al., 1996). And Kimm, et al. (2002) suggested that the difference of resting energy expenditure between African American and Caucasian women was related to uncoupling genes that were used for mitochondrial membrane transporters. Therefore, the specific equation based on the needs of different ethnicities should be developed for different ethnic groups, such as African Americans or Asians. Not considering ethnicity in predicting energy expenditure may lead to inappropriate recommendation for physical training and weight loss programs.

Interestingly the majority of previous research exploring energy expenditure by race and ethnicity has focused on resting energy expenditure or other PAEE, while energy expenditures during walking and running and their comparison among different ethnicities have received little attention. Data on physical activity was most related to age, sex, income occupation and education, but limited on ethnicity, because of the sample- size limitations for general population surveys (Stephens et al., 1985). So, very scarce research is available regarding physical activity energy expenditure in African Americans and Asians, especially walking and running energy expenditure. Furthermore, assessing energy expenditure plays an important role in designing training programs for weight management to avoid obesity. Therefore, the purpose of this study was to develop prediction equations of energy expenditure for African Americans, Asians, and three ethnic groups, and to validate these equations for specific ethnicity. And the secondary aim was to compare the differences in energy expenditures during walking and running corrected for one mile in African American normal weight and overweight adults, Asian normal weight and overweight adults, and three ethnic groups adults (including Caucasians, African Americans and Asians together).

Specific Aims:

Specific Aim 1:

To investigate if the predicted equations can accurately predict energy expenditure per mile in African Americans, Asians, Caucasians and combined ethnic groups together.

Specific Aim 2:

To compare the difference in energy expenditure during walking or running corrected for one mile among African American, Asian and Caucasian normal weight and overweight adults.

The following null hypotheses were tested:

H_{01a}: There will be no significant difference in predicted kcal/mile versus the measured kcal/mile in African American cross-validation group.

H_{01b}: There will be no significant difference in predicted kcal/mile versus the measured kcal/mile in Asian cross-validation group.

H_{01c}: There will be no significant difference in predicted kcal/mile versus the measured kcal/mile in three ethnic groups (including African Americans, Asians and Caucasians together) cross-validation group.

H_{01d}: There will be no significant difference in coefficients of original predicted equation versus the coefficients of predicted equation developed from African American cross-validation group.

H_{01e}: There will be no significant difference in coefficients of original predicted equation versus the coefficients of predicted equation developed from Asian cross-validation group.

H_{01f}: There will be no significant difference in coefficients of original predicted equation versus the coefficients of predicted equation developed from three ethnic cross-validation group (including African Americans, Asians and Caucasians).

H_{02a}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in African Americans.

H_{02b}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in African Americans.

H_{02c}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in African Americans.

H_{02d}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in African Americans.

H_{02e}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in African Americans.

H_{02f}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in African Americans.

H_{02g}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in African Americans.

H_{02h}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in African Americans.

H_{02i}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in African Americans.

H_{02j}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in Asians.

H_{02k}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in Asians.

H_{02l}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight walkers, overweight walkers and runners in Asians.

H_{02m}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in Asians.

H_{02n}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in Asians.

H_{02o}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight male walkers, overweight male walkers and male runners in Asians.

H_{02p}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in Asians.

H_{02q}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in Asians.

H_{02r}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among normal weight female walkers, overweight female walkers and female runners in Asians.

H_{02s}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among African Americans, Asians and Caucasians.

H_{02t}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among African Americans, Asians and Caucasians.

H_{02u}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among African Americans, Asians and Caucasians.

H_{02v}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among African Americans, Asians and Caucasians in males.

H_{02w}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among African Americans, Asians and Caucasians in males.

H_{02x}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among African Americans, Asians and Caucasians in males.

H_{02y}: There will be no significant difference in energy expenditure per mile during walking or running corrected for one mile among African Americans, Asians and Caucasians in females.

H_{02z}: There will be no significant difference in energy expenditure relative to body weight during walking or running corrected for one mile among African Americans, Asians and Caucasians in females.

H_{02A}: There will be no significant difference in energy expenditure relative to fat-free mass during walking or running corrected for one mile among African Americans, Asians and Caucasians in females.

CHAPTER 3

METHODOLOGY

1. Participants

The total number of African-American participants was sixty-eight, and the total number of Asian participants was eighty-five, which were separated into three groups: normal weight walking group, overweight walking group, and running group. Details are shown in Table 3.1. The 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.

The data for seventy-one Caucasians will be derived from other published studies in our laboratory (Loftin et al., 2010; Morris et al., 2014), including 35 males and 36 females or 26 normal weight walkers, 15 overweight walkers, and 30 runners.

2. Procedures

Before the energy expenditure 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 or running speeds. These preferred speeds were determined by evaluating their pace from six timed 70-foot trials on an indoor track. Participants were timed over the

Table 3.1: Distribution of African-American and Asian Participants

	African Americans			Asians		
	Male	Female	Total	Male	Female	Total
Normal Weight Walker	10	11	21	17	13	30
Overweight Walker	5	22	27	13	15	28
Runner	10	10	20	14	13	27
Total	25	43	68	44	41	85

middle 50 feet during each trail, and preferred pace was determined as the mean pace travelled over six trials in the manner previously described (Browning and Kram, 2005; Loftin et al., 2010; Morris et al., 2014). After a brief three minutes warm-up, participants were tested by walking or running at their preferred paces on a treadmill for five minutes duration. All metabolic data, oxygen uptake, carbon dioxide production, and pulmonary ventilation, was measured using a ParvoMedics TureOne 2400 (Sandy, UT) measurement system and accompanying mouthpiece and nose-clamp. Before metabolic tests, the system was calibrated against standard gases (O_2 = 16.0%, CO_2 = 4.0%). Indirect calorimetry was employed to measure the energy expenditure during walking and running on the treadmill, using oxygen uptake and respiratory exchange ratio, and was compared in absolute units (kilocalories) and kilocalories relative to mass (kcal·mile^{-1}kg·BW^{-1}) or fat-free mass (kcal·mile^{-1}kg·FFM^{-1}). The average oxygen uptake during the last two minutes was used and corrected to one-mile distance. Participants were required to avoid physical activity and ingestion of food and nutrients for at least 2 hours prior to testing. The males and females in three groups had the same activity patterns at their preferred paces.

3. Statistical Analyses:

Data was expressed as means ± standard error, and all analyses were conducted using SPSS software (Version 24, SPSS, Inc., Chicago, IL). Analysis of variance (ANOVA) was used for overall significance with post hoc Scheffe test employed to compare the energy expenditure during walking and running in three groups of African American or Asian adults, and among Caucasians, African Americans and Asians. Also, linear regression was used to predict the equations of energy expenditure in African Americans, in Asians and in the three ethnic groups. Finally, for cross-validation, the differences in measured energy expenditure of the cross-validation group and the predicted energy expenditure from the predicted equation were compared statistically by a dependent t-test. Regression coefficients generated from the cross-validation group were compared to the original equations coefficients using a Chow test, which is proposed by econometrician Gregory Chow in 1960 and is a test of whether the coefficients in two linear regressions on different data sets are equal. An alpha level of 0.05 was set to determine statistical significance.

CHAPTER 4

RESULTS

This results section included predicting equations for African Americans, Asians, and three ethnic groups (combined African Americans, Asians and Caucasians together), and cross- validation for these equations. Also, the absolute energy expenditure and relative energy expenditure, which was expressed relative to body weight and relative to fat-free mass, were compared in African American, Asian, and three ethnic groups adults, and were compared by different genders in these participants.

1 Predicted equations for walking or running one mile and cross-validation of the equations

1.1 Predicted equation for walking or running one mile in African Americans and cross-validation of the equation

The participants were randomly assigned to two groups. In one group, 42 African Americans, accounting for 62% of total, were used to develop one equation for predicting energy expenditure during walking or running one mile. And the other left 26 participants, accounting for 38% of total, served to cross-validate the predicted equation. The number of cross-validation accounted for 62% of validation group subjects.

1.1.1 Predicted equation of African Americans

Figure 4.1 shows a scatterplot of body weight and energy expenditure to walk or run one mile in African Americans irrespective of groups. The correlation was $r = 0.763$ ($R^2 = 0.582$). Predicting energy expenditure (kilocalories) during walking or running one mile yielded the following equation in African Americans: EE= 1.012BW - 9.233 Gender (M=1, F=2) + 47.188 (standard error of estimate, SEE = 14.6 $\text{kcal}\cdot\text{mile}^{-1}$).

1.1.2 Cross-validation of the equation

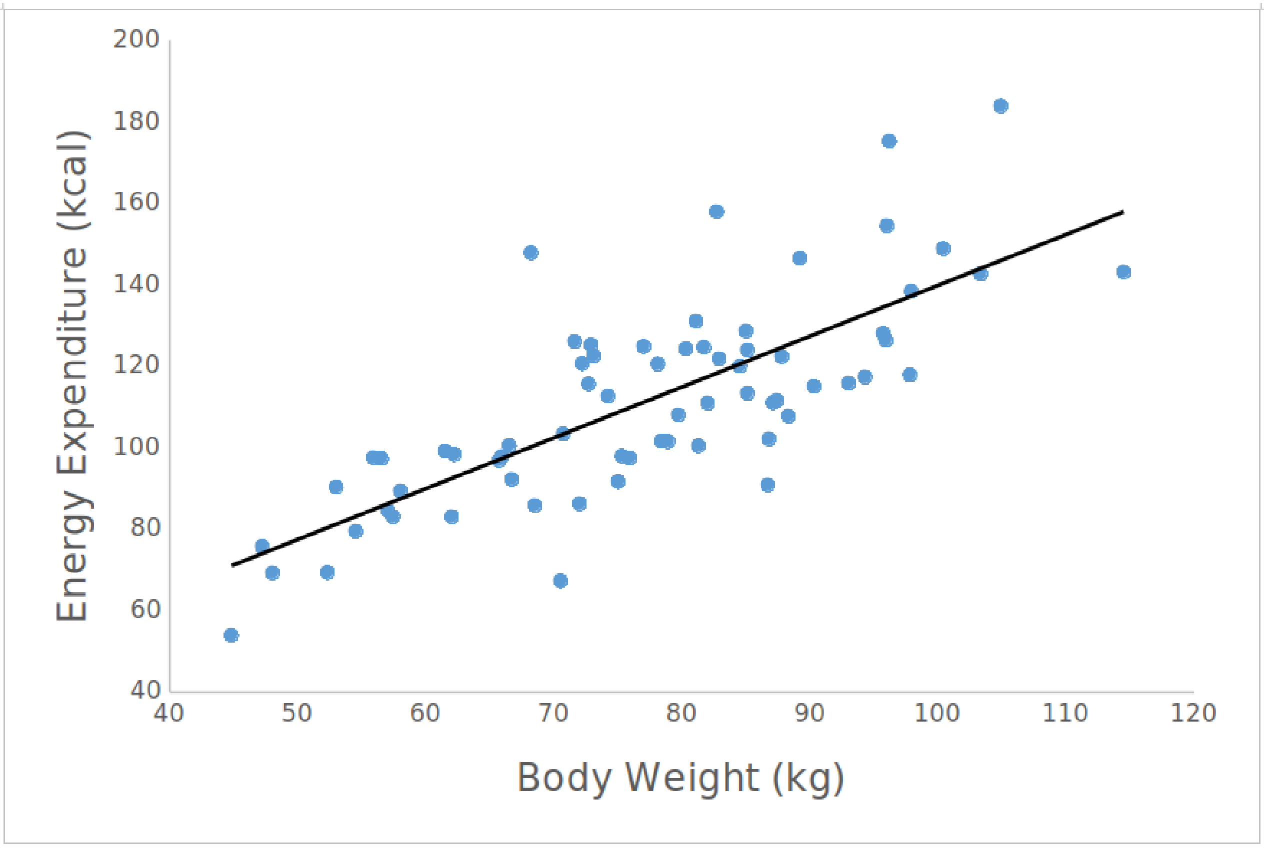

Figure 4.1. Scatterplot of body weight (kilograms) and energy expenditure (kilocalories) to walk or run one mile in African Americans (r = 0.763).

Table 4.1: Energy expenditure during walking or running one mile in African Americans cross-validation group

Variable	M	SE	Min	Max
Measured kcal·mile^{-1}	112.5	5.7	53.9	183.8
Predicted kcal·mile^{-1}	109.6	3.7	74.1	144.1

1.1.2.1 Dependent t-test

Table 4.1 indicates the energy expenditure during walking or running one mile in a cross-validation group of African Americans. The predicted energy expenditure was determined using the equation predicted above (EE= 1.012BW - 9.233 Gender (M=1, F=2) + 47.188). The mean of measured energy expenditure was 112.5 ± 5.7 kcal·mile^{-1}, and the mean of predicted energy expenditure was 109.6 ± 3.7 kcal·mile^{-1}. A dependent t-test revealed that there was no significant difference between measured and predicted values ($p > 0.05$).

1.1.2.2 Chow test

In cross-validation group, the correlation between predicted and measured energy expenditure was strong ($r = 0.831$, $R^2 = 0.691$). Using the data from the cross-validation group, a regression equation (EE= 1.246BW - 14.770 Gender (M=1, F=2) + 41.133) was estimated in order to compare coefficients with the predicted equation above (EE= 1.012BW - 9.233 Gender (M=1, F=2) + 47.188). The coefficient for body weight was 1.246 in the cross-validation group compared to 1.012 in the predicted equation. And the coefficient for gender was -14.770 in the cross-validation group compared to -9.233 in the predicted equation. The constant was 41.133 in cross-validation group compared to 47.188 in the predicted equation. The Chow test was used to compare the coefficients difference between these two equations. There was no significant difference for the coefficients of body weight and gender ($p = 0.636$). Figure 4.2 shows the predicted values through predicted equation and cross-validation equation.

1.2 Predicted equation for walking or running one mile in Asians and cross-validation of the equation

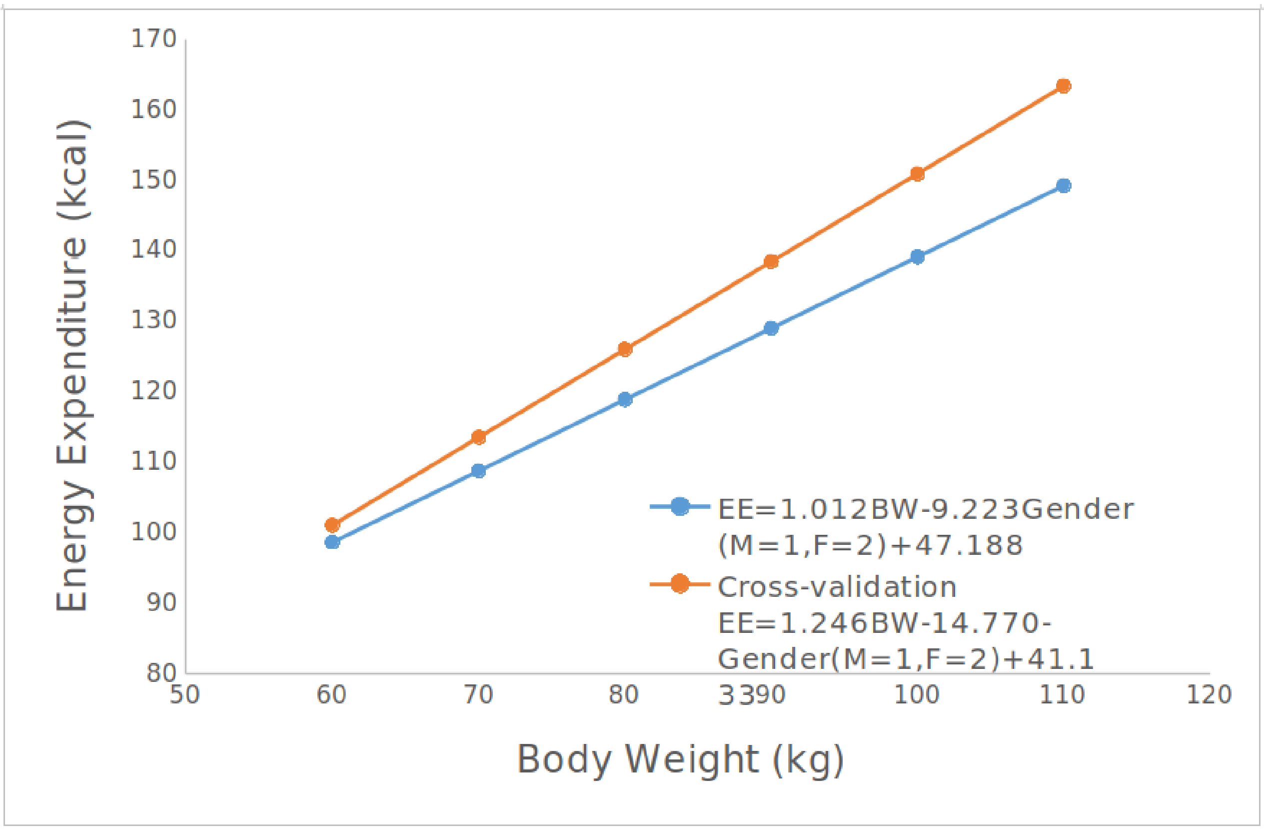

Figure 4.2. Predicting energy expenditure (kilocalories) based on body weight (kilocalories) in African Americans.

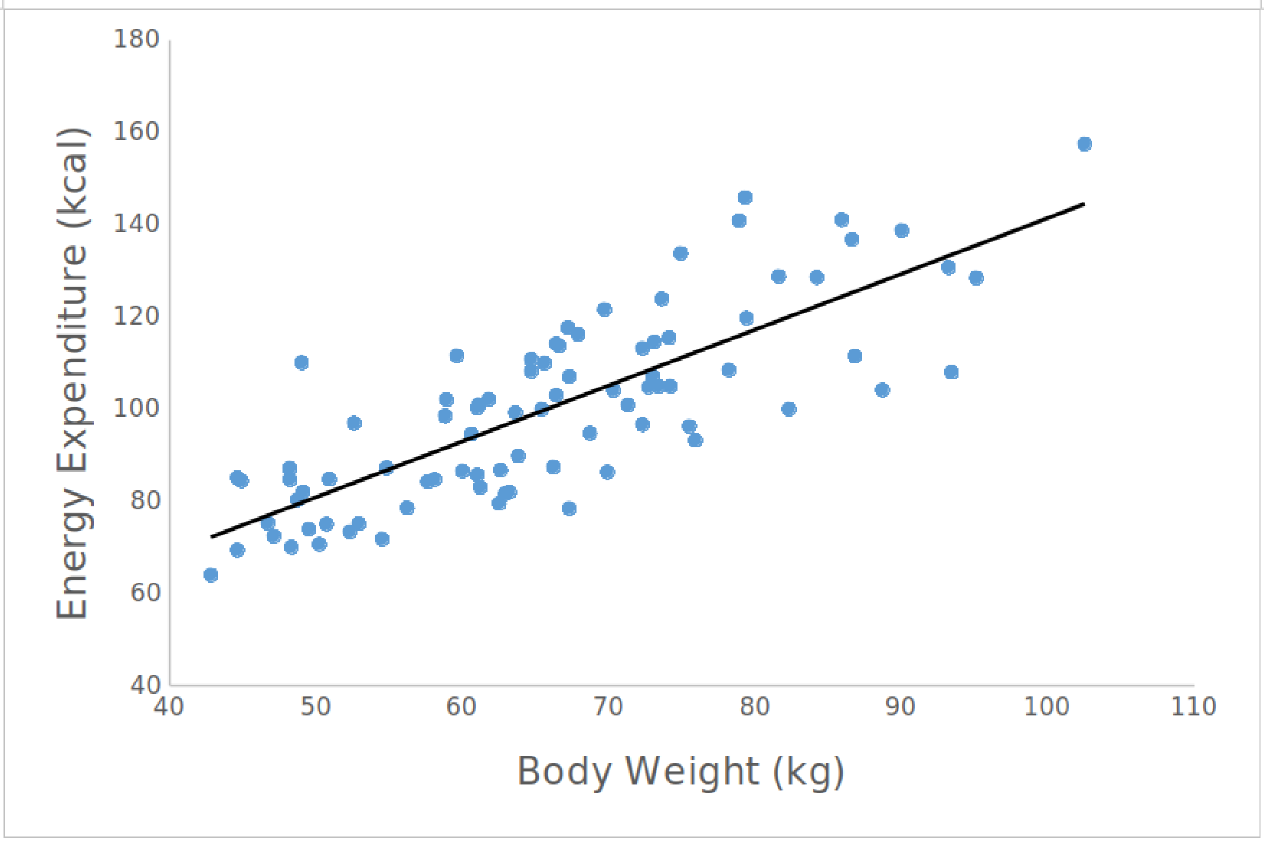

Figure 4.3. Scatterplot of body weight (kilograms) and energy expenditure (kilocalories) to walk or run one mile in Asians (r = 0.8).

A total of eighty-five Asian subjects were randomly assigned to a prediction equation group and the cross-validation group. In the prediction equation group, there were 53 Asians, accounting for 62% of total subjects. And in the cross-validation group, the 32 subjects left accounted for 38% of total Asians, and the number in cross-validation accounted for 60% of that in the prediction equation group.

1.2.1 Predicted equation of Asians

Figure 4.3 shows a scatterplot of body weight and energy expenditure to walk or to run one mile in Asians. The correlation was r = 0.8 ($R^2 = 0.64$). Predicting energy expenditure (kilocalories) during walking or running one mile yielded the following equation in Asians: EE= 0.933 BW - 4.127 Gender (M=1, F=2) + 44.256 (SEE=12.1 kcal·mile^{-1}).

1.2.2 Cross-validation of the equation

Table 4.2: Energy expenditure during walking or running one mile in Asians cross-validation group

Variable	M	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

1.2.2.1 Dependent t-test

The energy expenditure during walking or running one mile in the cross-validation group of Asians is presented in Table 4.2. The predicted energy expenditure was determined using the equation predicted above (EE= 0.933 BW - 4.127 Gender (M=1, F=2) + 44.256). The mean of measured energy expenditure was 101.4 ± 4.3 kcal·mile^{-1}, and the mean of predicted energy expenditure was 100.0 ± 2.8 kcal·mile^{-1}. A dependent t-test indicated that no significant difference between measured and predicted energy expenditure was found ($p > 0.05$).

1.2.2.2 Chow test

There was a strong correlation between predicted and measured energy expenditure in the cross-validation group ($r = 0.871$, $R^2 = 0.759$). Through the values in the cross-validation group, a regression equation (EE= 1.259 BW - 4.795 Gender (M=1, F=2) + 25.039) was predicted in order to compare coefficients with the predicted equation above (EE= 0.933 BW - 4.127 Gender (M=1, F=2) + 44.256). The coefficient for body weight was 1.259 in the cross-validation group compared to 0.933 in the predicted equation. And the coefficient for gender was -4.795 in the cross-validation group compared to -4.127 in the predicted equation. The constant was 25.039 in the cross-validation group compared to 44.256 in the predicted equation. The Chow test was used to compare the coefficients difference between these two equations. There was no significant difference in the coefficients of body weight and gender ($p = 0.365$). Figure 4.4 presented the predicted energy expenditure based on body weight through predicted equation and cross-validation equation.

1.3 Predicted equation for walking or running one mile for three ethnicities (Caucasians, African Americans and Asians) and cross-validation of the equation

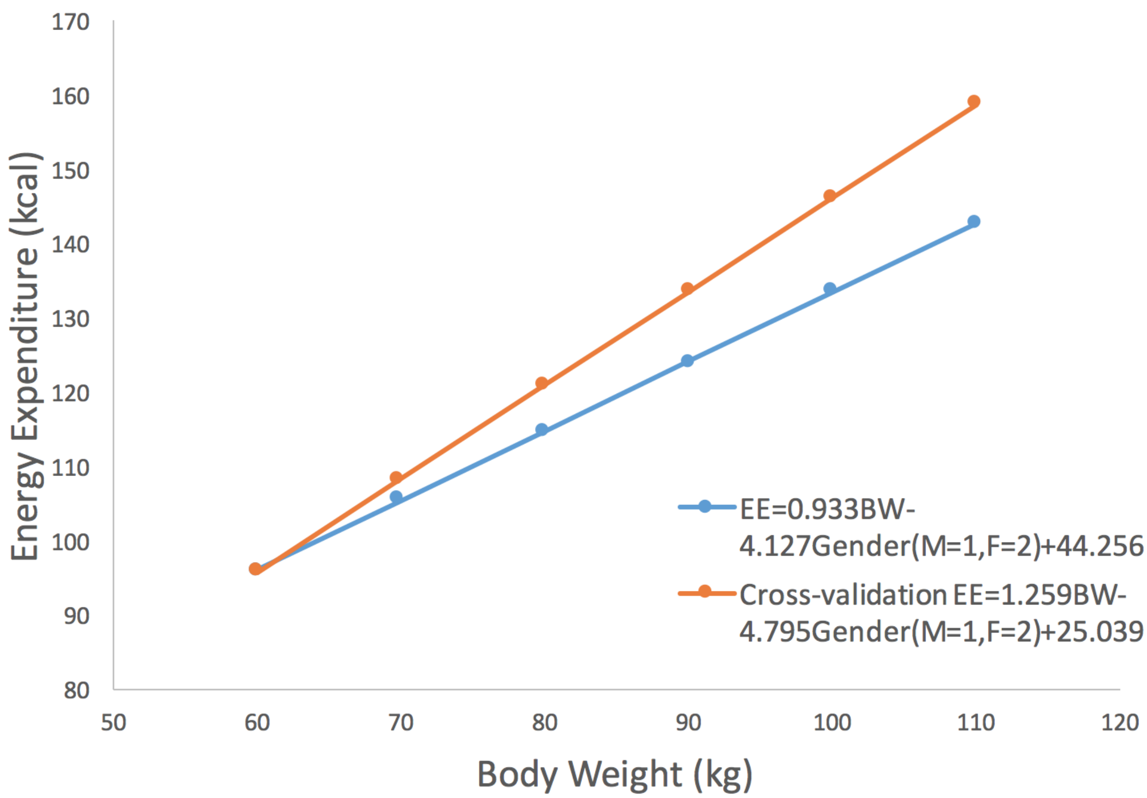

Figure 4.4. Predicting energy expenditure (kilocalories) based on body weight (kilocalories) in Asians.

Three ethnic groups, including Caucasians, African Americans and Asians, were randomly separated into two groups. One hundred and thirty-six subjects belonged to the predicted equation group, including 41 Caucasians, 42 African Americans and 53 Asians. And the eighty-eight left subjects were in cross-validation group, including 30 Caucasians, 26 African Americans and 32 Asians. The number of predicted group accounted for 61% of total subjects, and the number of cross-validation group accounted for 39% of total subjects. Comparing the numbers between predictive equation group and cross-validation group, the number in cross-validation group accounted for 65% of equation group.

1.3.1 Predicted equation of three ethnicities

Figure 4.5 shows a scatterplot of body weight and energy expenditure to walk or to run one mile in three ethnicities. The correlation was r = 0.775 ($R^2 = 0.6$). Predicting energy expenditure (kilocalories) during walking or running one mile yielded the following equation in Caucasians, African Americans and Asians: EE= 0.978 BW - 4.571 Gender (M=1, F=2) + 3.524 ethnicity (Caucasians=1, AA=2, Asians=3) + 32.447 (SEE=12.5 kcal·mile^{-1}).

1.3.2 Cross-validation of the equation

1.3.2.1 Dependent t-test

Table 4.3 presents the energy expenditure during walking or running one mile in the cross-validation group of Caucasians, African Americans and Asians. The predicted energy expenditure was determined using the equation predicted above (EE= 0.978 BW - 4.571 Gender (M=1, F=2) + 3.524 ethnicity (Caucasians=1, AA=2, Asians=3) + 32.447). The mean of measured energy expenditure was 106.9 ± 2.5 kcal·mile^{-1}, while the mean of predicted energy expenditure was 103.6 ± 1.7 kcal·mile^{-1}. A dependent t-test showed that the predicted equation significantly underestimated the energy expenditure during walking or running one mile in the cross-validation group ($p < 0.05$). However, the difference of energy expenditure (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.

1.3.2.2 Chow test

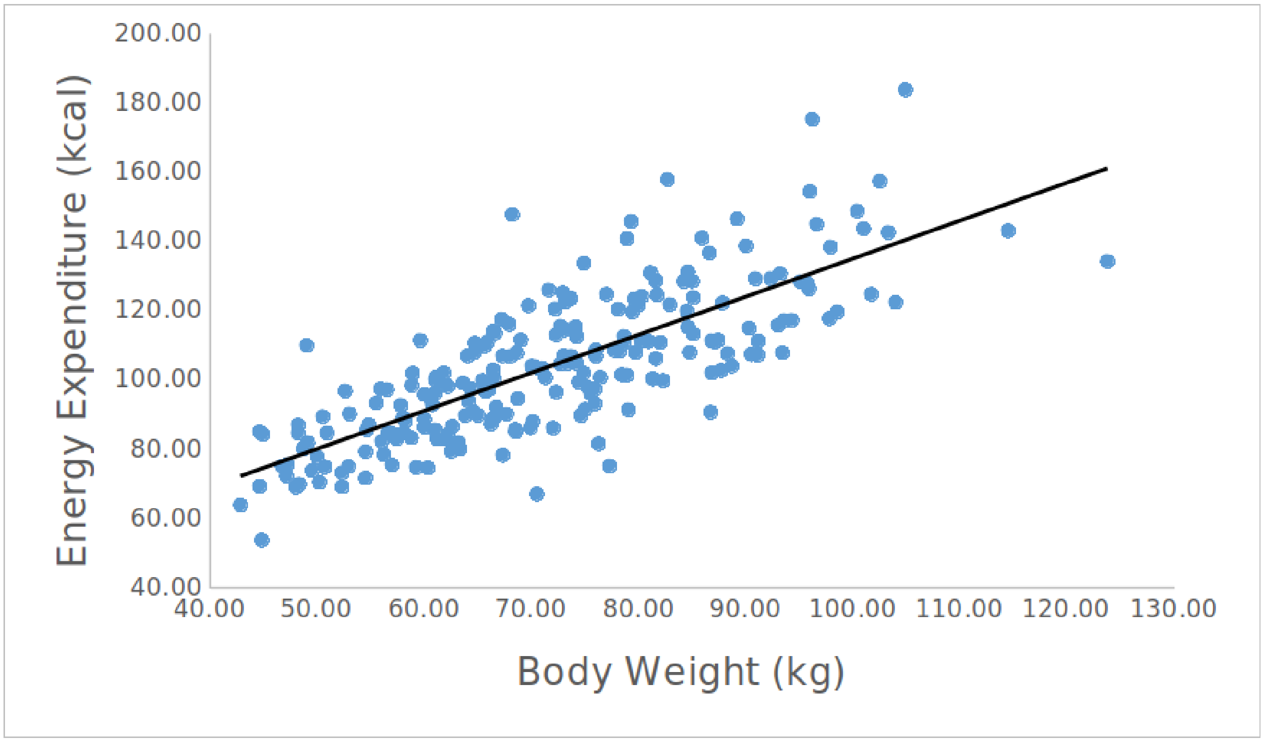

Figure 4.5. Scatterplot of body weight (kilograms) and energy expenditure (kilocalories) to walk or run one mile in Caucasians, AA and Asians (r = 0.775).

Table 4.3: Energy expenditure during walking or running one mile in three ethnicities cross-validation group

Variable	M	SE	Min	Max
Measured kcal·mile^{-1}	106.9	2.5	53.9	183.8
Predicted kcal·mile^{-1}	103.6	1.7	74.2	138.7

A strong correlation between predicted and measured energy expenditure in the cross-validation group (r = 0.822, R^2 = 0.676) was found. A regression equation (EE= 1.143 BW - 5.931 Gender (M=1, F=2) + 2.34 Ethnicity (Caucasians=1, AA=2, Asians=3) + 28.195) was predicted using data from the cross-validation group in order to compare coefficients with the predicted equation above (EE= 0.978 BW - 4.571 Gender (M=1, F=2) + 3.524 Ethnicity (Caucasians=1, AA=2, Asians=3) + 32.447). The coefficient for body weight was 1.143 in the cross-validation group compared to 0.978 in the predicted equation. And the coefficient for gender was -5.931 in the cross-validation group compared to -4.571 in the predicted equation. The coefficient for ethnicity was 2.34 in the cross-validation group compared to 3.524 in the predicted equation. And the constant was 28.195 in the cross-validation group compared to 33.447 in the predicted equation. The Chow test was used to compare the coefficients difference for body weight, gender and ethnicity between these two equations. There was no significant difference in the coefficients of body weight, gender and ethnicity (p = 0.589). Figure 4.6 indicated the predicted energy expenditure based on body weight through predicted equation and the cross-validation equation.

1.4 Random selection resampling

In order to validate the equation model, resampling method was applied by randomly select a subset of data in specific ethnic group for the model estimation. And the rest of data was used for validation equation through statistical software R. It was 1,000 times each time that run for random selection to run dependent t-test. Results showed that the percentage of significant difference was 18.9%, and the percentage of non-significant difference was 81.1% in African Americans. The percentage of significant difference was 11.9%, and the percentage of non-significant difference was 88.1% in Asians. And the percentage of significant difference was 14.7%, and the percentage of non-significant difference was 85.3% in three ethnic groups. And the program in R statistics software was attached in appendix.

2. Physical Characteristics and Energy Expenditure

2.1 African American physical characteristics and energy expenditure

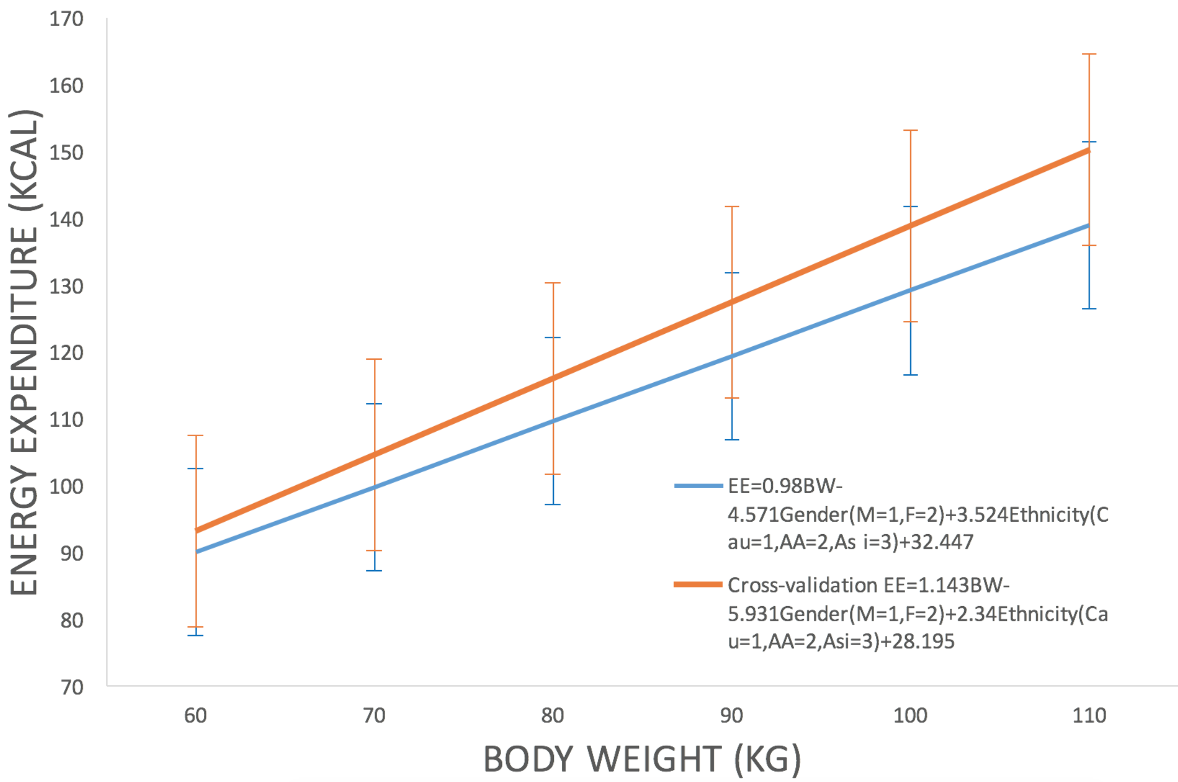

Figure 4.6. Predicting energy expenditure (kilocalories) based on body weight (kilocalories) in Caucasians, AA and Asians.

Table 4.4: Physical Characteristics in NWW, OW and R of African Americans

Variable	Group	Mean	SE	Min	Max
	NWW	20.9	0.2	19	23
Age(year)	OW	22.6	0.9	19	39
	R	21.4	0.4	19	26
	NWW	71.6^a	3.4	44.8	100.4
BW(kg)	OW	87.7^b	2.4	58	114.5
	R	72.7^a	3.4	47.2	104.9
	NWW	1.7	0.02	1.5	1.9
Height(m)	OW	1.6	0.02	1.5	1.9
	R	1.7	0.02	1.6	1.8
	NWW	19.8^a	1.4	9.7	30
%Fat	OW	35.6^b	1.0	25.4	44.5
	R	21.4^a	1.7	8.4	35
	NWW	3.4^a	0.08	2.6	4.0
Preferred Speed	OW	3.4^a	0.08	2.4	4.1
	R	7.0^b	0.29	5.0	9.5
	NWW	13.7^a	1.1	5.8	21.8
FM(kg)	OW	29.7^b	1.4	19.6	49.4
	R	15.3^a	1.5	6.0	27.8
	NWW	56.5	3.0	32.9	76.3
FFM(kg)	OW	53.5	1.6	37.1	69.8
	R	56.0	2.8	37.6	83.1

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

2.1.1 African American physical characteristics

The results presented in Table 4.4 refer to the physical characteristics of AA participants. As expected, significant difference in BW, fat percentage and fat mass were noted, with overweight group exhibiting significantly higher value than normal weight walker and runner groups. Also, the preferred speed in running group was significantly higher than the other two groups, as expected. And age, height and FFM were similar across the three groups, as no significant difference in them as well.

2.1.2 African American energy expenditure

2.1.2.1 Energy expenditure in NWW, OW and R groups

In Table 4.5, the results show energy expenditure during walking or running one mile in African Americans. The data suggested that normal weight walker group expended

Table 4.5: Energy expenditure during walking or running one mile in NWW, OW and R groups of African Americans

Variable	Group	Mean	SE	Min	Max
	NWW	98.5^a	4.7	53.9	148.8
kcal·mile^{-1}	OW	115.5	3.7	67.2	154.4
	R	119.0^b	6.8	69.2	183.8
	NWW	1.4^a	0.04	1.0	1.7
kcal·mile^{-1}kg·BW^{-1}	OW	1.4^a	0.03	1.0	1.7
	R	1.6^b	0.04	1.4	2.2
	NWW	1.8^a	0.06	1.2	2.2
kcal·mile^{-1}kg·FFM^{-1}	OW	2.2^b	0.06	1.6	2.7
	R	2.1^b	0.06	1.7	2.7

significantly lower energy than runner group with no difference compared to overweight group at the preferred walking or running pace. And another significant difference was added between overweight and runner groups when the energy expenditure was expressed relative to body weight. Meanwhile, a different pattern emerged when energy expenditure was expressed relative to FFM with normal weight walker group expending significantly lower energy than overweight group or runner group, but no difference was shown between overweight and runner groups.

2.1.2.2 Body weight, FM, FFM and energy expenditure by gender

Table 4.6 included the body weight, FM, FFM, and energy expenditure during walking or running one mile by gender in African Americans. As noted, the body weight of males was significantly higher than females, as well as for FFM. But the FM in males was lower than females. Also, absolute energy expenditure in males was significantly higher than that of females. However, the males expended significantly lower than females when the energy expenditure was expressed relative to FFM. And no difference was found by gender if the energy expenditure was expressed relative to BW.

Specifically, in females, body weight in the overweight group was higher than normal weight walker group or runner group, with no difference between normal weight walker and runner groups. And for males, there were significant differences between normal weight walker and runner groups wherever the absolute energy expenditure or energy expenditure was expressed relative to BW or relative to FFM. Meanwhile, another significant difference was shown between overweight and runner groups when energy expenditure was expressed relative to BW. In females, data indicated that normal weight walker group expended significantly lower energy than the overweight group. When energy expenditure was expressed relative to FFM, another difference between normal weight walker and runner groups was added. However, the significant difference between overweight and runner groups was noted when energy expenditure was expressed relative to BW. In FM, whether male or female, the overweight group was significantly higher than normal weight walker or runner group.

2.2 Asian physical characteristics and energy expenditure

2.2.1 Asian physical characteristics

Physical characteristics of three groups in Asians are presented in Table 4.7. As noted, similar results were shown in fat percentage, fat mass and preferred speed as African Americans, except no significant difference was found in BW among groups.

2.2.2 Asian energy expenditure

2.2.2.1 Energy expenditure in NWW, OW, and R groups

Table 4.8 presents data relating the energy expenditure in Asians. The data indicates that normal weight walker group expended similar absolute energy (kcal·mile^{-1}) as overweight group or runner group at preferred speed. When absolute energy expenditure was expressed relative to BW, runner group was found to expend more energy than the other two groups. However, when the absolute energy expenditure was expressed relative to FFM, the significant difference between overweight and runner groups was disappeared, only the difference between normal weight walker and runner groups was left.

2.2.2.2 BW, FM, FFM and energy expenditure by gender

As shown in Table 4.9, there is significant difference in BW between males and females. And the FFM of males was significantly higher than that of females. No difference was shown on FM between genders. The differences of absolute energy expenditure and en-

Table 4.6: Physical characteristics and energy expenditure during walking or running one mile by gender in NWW, OW and R groups of African Americans

Variable	Gend	Mean	SE	Group	M	SE
BW	M	84.6^a	2.1	NWW	83.5	3.6
				OW	90.1	2.1
				R	82.9	3.5
	F	72.8^b	2.5	NWW	60.8^a	2.9
				OW	83.5^b	2.8
				R	62.6^a	3.6
FM	M	16.0^a	1.4	NWW	13.7^a	1.8
				OW	24.4^b	1.0
				R	14.3^a	2.1
	F	23.1^b	1.6	NWW	13.7^a	1.4
				OW	30.9^b	1.6
				R	16.4^a	2.2
FFM	M	66.7^a	1.4	NWW	68.2	2.4
				OW	63.5	1.7
				R	66.9	2.3
	F	48.4^b	1.1	NWW	45.8	2.3
				OW	51.3	1.6
				R	45.0	1.5
kcal·mile^{-1}	M	126.9^a	4.5	NWW	114.9^a	5.4
				OW	122.8	7.3
				R	140.9^b	7.6
	F	102.2^b	3.3	NWW	83.7^a	3.9
				OW	113.8^b	4.2
				R	97.2	5.7
kcal·mile^{-1}kg·BW^{-1}	M	1.5	0.05	NWW	1.4^a	0.06
				OW	1.4^a	0.08
				R	1.7^b	0.07
	F	1.4	0.03	NWW	1.4	0.05
				OW	1.4^a	0.04
				R	1.6^b	0.05
kcal·mile^{-1}kg·FFM^{-1}	M	1.9^a	0.07	NWW	1.7^a	0.09
				OW	1.9	1.1
				R	2.1^b	0.1
	F	2.1^b	0.04	NWW	1.8^a	0.07
				OW	2.2^b	0.06
				R	2.1^b	0.07

Table 4.7: Physical Characteristics in NWW, OW and R groups of Asians

Variable	Group	Mean	SE	Min	Max
	NWW	37.7	2.2	18	60
Age(year)	OW	38.4	1.7	22	54
	R	32.4	2.2	18	55
	NWW	63.7	2.5	42.8	95.1
BW(kg)	OW	70.9	2.4	48.7	93.4
	R	63.2	2.5	44.6	102.5
	NWW	1.7	0.02	1.5	1.8
Height(m)	OW	1.7	0.02	1.6	1.9
	R	1.7	0.02	1.5	1.8
	NWW	23.3^a	0.7	15.1	30
%Fat	OW	31.5^b	0.8	25.1	41.7
	R	24.4^a	1.5	11.5	38.8
Preferred Speed	NWW	3.6^a	0.06	2.9	4.3
	OW	3.5^a	0.08	2.5	4.3
	R	6.3^b	0.2	4.0	8.0
	NWW	14.4^a	0.6	8.5	21.8
FM(kg)	OW	21.7^b	0.7	15.1	30.0
	R	14.9^a	1.0	6.6	26.5
	NWW	48.0	2.0	31.7	71.4
FFM(kg)	OW	47.8	1.9	32.4	66.8
	R	47.2	2.2	29.6	73.9

Table 4.8: Energy expenditure during walking or running one mile in NWW, OW and R groups of Asians

Variable	Group	Mean	SE	Min	Max
	NWW	93.8	3.7	64.0	145.8
$\text{kcal}\cdot\text{mile}^{-1}$	OW	101.5	3.8	73.3	141.0
	R	115.8	3.7	69.4	157.4
	NWW	1.5^a	0.04	1.2	2.2
$\text{kcal}\cdot\text{mile}^{-1}\text{kg}\cdot\text{BW}^{-1}$	OW	1.4^a	0.03	1.2	1.7
	R	1.7^b	0.03	1.2	1.9
	NWW	2.0^a	0.05	1.6	3.0
$\text{kcal}\cdot\text{mile}^{-1}\text{kg}\cdot\text{FFM}^{-1}$	OW	2.1	0.05	1.6	2.6
	R	2.3^b	0.05	1.6	2.8

ergy expenditure relative to FFM in males and females could be found similarly as African Americans.

Specifically, the BW in the overweight group was significantly higher than the runner group in males. But in females, the BW of overweight group was significantly higher than the normal weight walker group. And in males, absolute energy expenditure was similar across three groups. When absolute energy expenditure was expressed relative to BW, runner group was found to expend more energy than the other two groups. However, when absolute energy expenditure was expressed relative to FFM, only difference between normal weight walker and runner groups existed with disappearing of difference between overweight and runner groups. The similar absolute energy expenditure was found in females as males. And when the energy expenditure was expressed relative to BW, there was significant different between overweight and runner groups. Another difference was added between normal weight walker and runner groups when energy expenditure was expressed relative to FFM. In FM, whether males or females, the overweight group was significantly higher than normal weight walker or runner groups.

2.3 Physical characteristics and energy expenditure in three ethnicities

2.3.1 Comparison of physical characteristics in Caucasians, African Americans, and Asians

In Table 4.10, the comparison of physical characteristics in Caucasians, African Americans, and Asians was presented. The significant difference of age among three ethnicities was noted. Also, body weight between Caucasians and Asians or between African Americans and Asians was significantly different, while there was no difference between Caucasians and Asians. As for height, Caucasians was significantly higher than both African Americans and Asians, with no significance between them. The FM of African Americans was significantly higher than Caucasians and Asians. The FFMs in Caucasians and African Americans were significantly higher than that of Asians. No difference in %Fat and preferred speed were shown.

2.3.2 Comparison of energy expenditure in Caucasians, African Americans, and Asians

Table 4.9: Physical characteristics and energy expenditure during walking or running one mile by gender in NWW, OW, and R groups of Asians

Variable	Gend	Mean	SE	Group	M	SE
BW	M	74.9^a	1.6	NWW	73.0	2.4
				OW	81.6^a	2.4
				R	71.1^b	3.0
	F	56.2^b	1.3	NWW	51.5^a	1.9
				OW	61.6^b	1.9
				R	54.8	2.2
FM	M	16.9	0.8	NWW	15.5^a	0.8
				OW	22.6^b	1.0
				R	13.3^a	1.3
	F	17.0	0.8	NWW	13.0^a	0.7
				OW	20.8^b	1.0
				R	16.7^a	1.3
FFM	M	56.7^a	0.9	NWW	56.2	1.6
				OW	57.4	1.6
				R	56.6	1.8
	F	38.0^b	0.7	NWW	37.3	1.4
				OW	39.5	1.1
				R	37.0	1.2
kcal·mile^{-1}	M	112.0^a	2.8	NWW	104.3	4.4
				OW	115.0	5.4
				R	118.4	4.3
	F	87.5^b	2.1	NWW	80.1	3.6
				OW	89.7	3.2
				R	92.2	3.3
kcal·mile^{-1}kg·BW^{-1}	M	1.5	0.03	NWW	1.4^a	0.04
				OW	1.4^a	0.05
				R	1.7^b	0.04
	F	1.6	0.03	NWW	1.6	0.07
				OW	1.5^a	0.04
				R	1.7^b	0.03
kcal·mile^{-1}kg·FFM^{-1}	M	2.0^a	0.04	NWW	1.9^a	0.05
				OW	2.0	0.08
				R	2.1^b	0.05
	F	2.3^b	0.04	NWW	2.2^a	0.09
				OW	2.3^a	0.05
				R	2.5^b	0.04

Table 4.10: Physical characteristics in Caucasians, African Americans, and Asians

Variable	Ethnicity	Mean	SE	Min	Max
	Caucasian	31.1^a	1.3	18	64
Age(year)	AA	21.7^b	0.4	19	39
	Asian	36.3^c	1.2	18	60
	Caucasian	73.8^a	1.7	50	123.8
BW(kg)	AA	77.1^a	1.9	44.8	114.5
	Asian	65.9^b	1.5	42.8	102.5
	Caucasian	1.72^a	0.01	1.3	2.0
Height(m)	AA	1.67^b	0.01	1.5	1.9
	Asian	1.68^b	0.01	1.5	1.9
	Caucasian	23.3	1.0	7.4	43.7
%Fat	AA	26.5	1.2	8.4	44.5
	Asian	26.4	0.7	11.5	41.7
	Caucasian	4.6	0.2	2.4	9.0
Preferred Speed	AA	4.4	0.2	2.4	9.5
	Asian	4.4	0.2	2.5	8.0
	Caucasian	15.9^a	1.0	4.7	44.5
FM(kg)	AA	20.5^b	1.2	5.8	49.4
	Asian	17.0^a	0.6	6.6	30.0
	Caucasian	56.0^a	1.3	38.1	84.3
FFM(kg)	AA	55.1^a	1.4	32.9	83.1
	Asian	47.7^b	1.2	29.6	73.9

Table 4.11: Energy expenditure during walking or running one mile in Caucasians, African Americans, and Asians

Variable	Ethnicity	Mean	SE	Min	Max
	Caucasian	102.3^a	2.0	74.7	145.0
kcal·mile^{-1}	AA	111.3^b	3.0	53.9	183.8
	Asian	100.2^a	2.2	64.0	157.4
	Caucasian	1.40^a	0.02	1.0	1.8
kcal·mile^{-1}kg·BW^{-1}	AA	1.45^a	0.03	1.0	2.2
	Asian	1.53^b	0.02	1.2	2.2
	Caucasian	1.9^a	0.03	1.4	2.7
kcal·mile^{-1}kg·FFM^{-1}	AA	2.0^b	0.04	1.2	2.7
	Asian	2.1^b	0.03	1.6	3.0

2.3.2.1 Energy expenditure in Caucasians, African Americans, and Asians

In the comparison of energy expenditure in three ethnicities, as shown in Table 4.11, the absolute energy expenditure of Caucasians and Asians were significantly lower than that of African Americans, with similar results between Caucasians and Asians. However, when absolute energy expenditure was expressed relative to body weight, results were found to be similar between Caucasians and African Americans, while the difference between African Americans and Asians was still significant, and there was a significant difference between Caucasians and Asians. If the absolute energy expenditure was expressed relative to FFM, another difference was noted. The value of Caucasians was significantly lower than that of African Americans and Asians, but there was no difference between African Americans and Asians.

2.3.2.2 Energy expenditure by gender in Caucasians, African Americans and Asians

In Table 4.12, data indicates that the BW and FFM in males were significantly higher than that of females. But the FM in males was significantly lower than females. And the absolute energy expenditure of males was significantly higher than that of females. Meanwhile, the results were adverse when absolute energy expenditure was expressed relative to FFM. And there was no difference in energy expenditure relative to BW by gender.

Specifically, for BW, there was significant difference between African American and

Asian males, and the Asian group was significantly lower than Caucasians and African Americans. The difference of FM in gender was shown by females. The FM in African American females was significantly higher than that in Caucasians and Asians, which was the same as the total comparison, with no difference in male subjects. About FFM, whether males or females, the values of Asians were significantly lower than that of Caucasians and African Americans. And in males, Caucasians and Asians expended significantly lower energy than African Americans, with similar results between Caucasians and Asians. However, when energy expenditure was expressed relative to BW, there were significant difference between Caucasians and Asians instead of between African Americans and Asians. A similar difference was found in energy expenditure relative to FFM. In females, about the absolute energy expenditure, there were significant differences between Caucasians and Asians and between African Americans and Asians, with no difference between Caucasians and African Americans. A similar difference happened when energy expenditure was expressed relative to BW. Except the difference, the significant difference among three ethnicities were shown when energy expenditure relative to FFM.

Table 4.12: Physical characteristics and energy expenditure during walking or running one mile by gender in Caucasians, African Americans, and Asians

Variable	Gender	Mean	SE	Ethnicity	M	SE
BW	M	79.2^a	1.2	Caucasian	80.8	2.2
				AA	84.6^a	2.1
				Asian	74.9^b	1.6
	F	65.4^b	1.3	Caucasian	67.0^a	2.1
				AA	72.8^a	2.5
				Asian	56.2^b	1.3
FM	M	15.9^a	0.7	Caucasian	14.5	1.3
				AA	16.0	1.4
				Asian	16.9	0.8
	F	19.3^b	0.8	Caucasian	17.3^a	1.5
				AA	23.1^b	1.6
				Asian	17.0^a	0.8
FFM	M	61.9^a	0.8	Caucasian	65.1^a	1.2
				AA	66.7^a	1.4
				Asian	56.7^b	0.9
	F	44.5^b	0.7	Caucasian	47.1^a	0.9
				AA	48.4^a	1.1
				Asian	38.0^b	0.7
kcal·mile^{-1}	M	113.1^a	2.0	Caucasian	104.2^a	2.1
				AA	126.9^b	4.5
				Asian	112.0^a	2.8
	F	96.8^b	1.8	Caucasian	100.6^a	3.2
				AA	102.2^a	3.3
				Asian	87.5^b	2.1
kcal·mile^{-1}kg·BW^{-1}	M	1.5	0.02	Caucasian	1.38^a	0.03
				AA	1.50	0.05
				Asian	1.50^b	0.03
	F	1.5	0.02	Caucasian	1.42^a	0.03
				AA	1.42^a	0.03
				Asian	1.57^b	0.03
kcal·mile^{-1}kg·FFM^{-1}	M	1.9^a	0.03	Caucasian	1.8^a	0.04
				AA	1.9	0.07
				Asian	2.0^b	0.04
	F	2.1^b	0.03	Caucasian	1.9^a	0.04
				AA	2.1^b	0.04
				Asian	2.3^c	0.04

CHAPTER 5

DISCUSSION

Knowledge and assessment of physical activity is not only beneficial for physical training but also helpful for exercise programs for weight management. In this section, several factors, such as body weight, height, gender, walking or running speed are discussed as independent variables in predicting energy expenditure in African Americans, Asians and three ethnic groups (combined African Americans, Asians and Caucasians together). Also, through cross-validation, these equations were discussed if they were valid for predicting energy expenditure during walking or running corrected for one mile. Additionally, the comparison of energy expenditure was discussed in different groups (normal weight walkers, overweight walkers, and runners), genders and ethnicities.

1. The predicted equations for African Americans, Asians, Caucasians, and three ethnic groups (including Caucasians, African Americans and Asians combined together)

When designing physical activity interventions of weight management for overweight or obese adults, it is essential to know the energy expenditure during exercise. Also, it would be convenient for clinicians to predict energy expenditure in exercise prescription just based on some easily obtained variables, such as body weight or gender. Several methods have been developed for determining resting or physical activity energy expenditure, including indirect calorimetry, direct calorimetry, doubly labeled water and predictive equations. Among these methods, even though many were considered as gold standard methods, such as direct calorimetry, respiratory indirect calorimetry and doubly labeled water, they were impracticable in a field study. Thus, the method of predictive equations with the advantage of simple, fast and low cost was developed by some researchers (Pinheiro Volp et al., 2011).

The first productive equation was published in 1919 by Harris and Benedict (Harris and Benedict, 1919). Then, several equations were derived by other authors through the methods of respiratory indirect calorimetry or doubly labeled water (Case et al., 1997; Compher et al., 2004; Daly et al., 1985; Leung et al., 2000; Liu et al., 1995; Mifflin et al., 1990; Spears et al., 2009; Wouters-Adriaens and Westerterp, 2008). But most of the predictive equations were focused on REE, and less were focused on energy expenditure of physical activity.

However, these predictive equations should be evaluated with caution, because ethnicity diversity of subjects was ignored by most investigators. Due to predicting equations were commonly derived from Caucasian subjects, the data on REE prediction in other ethnicities were not accurate (Weijs, 2008). Some equations overestimated energy expenditure (Daly et al., 1985; Mifflin et al., 1990; Spears et al., 2009; Wouters-Adriaens and Westerterp, 2008), and others underestimated energy expenditure (Spears et al., 2009). In a study of 502 Caucasian and African American girls and boys aged 6-11 years, McDuffie et al. (2004) showed that previously developed prediction equations were not accurate for REE in African American children. Also, Case, Brahler, and Heiss (1997) and Leung, Woo, Chan, Tang (2000) validated the equations in Asian subjects and found that most equations were not accurate with exception of the Liu equation (Liu et al., 1995) which was developed from Chinese participants. Some experts also suggested that only a single equation could not predict energy expenditure for all ethnic groups (Torun et al., 1996). Also, Kimm, et al. (2002) suggested that the difference of resting energy expenditure between African American and Caucasian women was related to uncoupling genes which were used for mitochondrial membrane transporters. Therefore, specific equations based on the needs of different ethnicities should be derived in different ethnic groups, such as African Americans or Asians. Without considering ethnicity during predicting energy expenditure may lead to inappropriate recommendation for physical training and weight loss.

Liu, Lu, and Chen (1995) reported that current predictive equations for basal metabolic rate were overestimated for healthy Chinese adults. The result of the current study showed that the energy expenditure in African Americans was significantly higher than that in Caucasians. So the predicting equation for energy expenditure was likely to underestimate values of energy in African Americans. Fellingham, Roundy, Fisher, and Bryce (1978) developed an equation for walking (EE= 3.7104 + 0.2678BW +0.0359 $Speed^2$BW). When input data in the current study into their equation of walking, after calculating, the predicted energy expenditure was significantly lower than measured values for African Americans (data was not shown). This result was also noted in Asians. Thus, the equation derived from one population, such as Caucasians, may not apply into another population appropriately, because the different ethnicities contributed to different metabolic rate.

1.1 The factors influence the predicted equations

In the current study, several factors influenced energy expenditure during physical activity. Body weight had the strongest relationship with energy expenditure among all factors (African American: r= 0.763; Asian: r= 0.80; three ethnic group: r= 0.775). Heden, LeCheminant, and Smith (2012) categorized the body weight as normal weight and overweight, and examined the influence on energy expenditure prediction. They noted that the importance of weight classification was highlighted for the accuracy of energy expenditure when equations were used for assessing energy expenditure, due to overestimation of energy expenditure in overweight women. The result of a strong relationship between body weight and energy expenditure was also supported by other researchers (Epstein et al., 1987; Foster et al., 1997; Pandolf et al., 1977; Van der Walt and Wyndham, 1973). Foster, Wadden, and Vogt (1997) reported that weight alone accounted for 46% variance of resting energy expenditure which was the largest amount variance of REE.

Height was possibly considered as one factor to effect the energy prediction. In the current study, when adding height into prediction equation, the change of the equations was almost zero (African Americans: ΔR^2= 0.001; Asians: ΔR^2= 0.004; three ethnic groups: ΔR^2= 0). So height was not considered as factor in the equation developed.

Preferred speed might be another factor to influence the predictive equation of energy expenditure. In the current study, the relationship between preferred speed and energy expenditure (African Americans: R^2= 0.05; Asians: R^2= 0.11; three ethnic groups: R^2= 0.03) was much less than the relationship between body weight and energy expenditure (African Americans: R^2= 0.58; Asians: R^2= 0.64; three ethnic groups: R^2= 0.60). This result echoed what was published in previous research (Fellingham et al., 1978; Kram and Taylor, 1990; Van der Walt and Wyndham, 1973), suggesting that energy expenditure was independent of speed. It was probably influenced by stride length and leg length, which did not significantly influence energy expenditure and only accounted for 2% of total variance. On the other hand, two equations developed by Epstein, Stroschein and Pandolf, which showed that energy expenditure was related to speed (Epstein et al., 1987; Pandolf et al., 1977). Another equation with step frequency instead of speed was derived by Sun et al. (2013).

Some investigators suggested that fat mass and/ or FFM played an important role in energy expenditure prediction equations (Foster et al., 1997; Kaplan et al., 1996). Wouters-Adriaens and Westerterp (2008) noted that the body composition, specifically fat percentage, was one reason of overestimating energy expenditure in Asians who compared to Caucasians. Meanwhile, the result in the current study showed that adding FFM to the prediction equation added very little (African Americans: ΔR^2= 0.001; Asians: ΔR^2= 0.021; three ethnic groups: ΔR^2= 0). However, when FFM was considered as the only predictive variable, it accounted for much of the percentage of energy expenditure variance (African Americans: R^2= 0.47; Asians: R^2= 0.63; three ethnic groups: R^2= 0.50). So after adding FFM into equation, there was nearly not any change in the new predictive equation, as body weight included body composition components (fat-free mass and fat mass).

Also, the subjects fitness level (trained and untrained), grade and terrains (track and treadmill) were considered as factors into predicting the equation. But it was not useful to develop specific regression equations for trained and untrained subjects, because the trained runners do not always exhibit good running economy (Leger and Mercier, 1984). Also, no significant difference of energy expenditure between track and treadmill running was found by Hall, Figueroa, Fernhall and Kanaley, (2004).

In the energy expenditure prediction equation for three ethnic groups, body weight and gender accounted for the most variance in the prediction equation (R^2= 0.616). Also, after adding the factor of ethnicity, the relationship between factors and equation increased (R^2= 0.628). So the factor of ethnicity accounts for 1.2% for equation before or after adding ethnicity (ΔR^2= 0.012). It may suggest that ethnicity plays some roles in developing equation for different populations.

Because body weight and gender accounted for most of the percentage of energy expenditure variance (African Americans: R^2= 0.625; Asians: R^2= 0.643; three ethnic groups: R^2= 0.616), the body weight and gender were considered as contributors to predict energy expenditure during walking or running one mile in African American, Asian, and three ethnic groups adults. In the prediction equations, body weight accounted for 58.2% of the variance with gender adding another 4.4% in African Americans, accounted for 63.9% of the variance with gender adding another 0.4% in Asians, and accounted for 60% of the variance with gender adding another 1.6% in three ethnic groups (Caucasians, African Americans and Asians together). These findings were consistent with previous studies reported by Loftin et al. (2010), who developed the regression model (kcal= mass (kg)*0.789 - gender (men=1, women=2) * 7.6734 +51.109) to predict energy expenditure for a give 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 (Loftin et al., 2010). Meanwhile, Morris et al. (2014) validated Loftins prediction equation with 30 subjects (10 normal weight walkers, 10 overweight walkers and 10 distance runners) and recommended the equation to predict energy expenditure to run or walking a mile.

In the current study, the equations were developed during walking or running corrected for one mile for specific ethnic groups as following:

African Americans: EE= 1.012BW - 9.233 Gender (M=1, F=2) + 47.188 (SEE = 14.6

kcal·mile^{-1});

Asians: EE= 0.933 BW - 4.127 Gender (M=1, F=2) + 44.256 (SEE=12.1 kcal·mile^{-1});

Three ethnic groups: EE= 0.978 BW - 4.571 Gender (M=1, F=2) + 3.524 ethnicity (Caucasians=1, AA=2, Asians=3) + 32.447 (SEE=12.5 kcal·mile^{-1}).

1.2. Cross-validation for the equations of African Americans, Asians, Caucasians and three ethnic groups

1.2.1 Cross-validation for the equation of African Americans

Through a dependent t-test, the non-significant difference between measured energy expenditure and the predicted values in a cross-validation group showed that there was no difference for predicted values through the equation. Also, the Chow test was used for comparing the coefficients between two equations. Result showed that there was no significant difference between two coefficients of these two equations (p= 0.636). In Figure 4.2, there were a similar trends of regression slopes between the predicted equation and the cross-validation equation.

So, the results in the cross-validation group provided sufficient support to demonstrate that the derived equation for predicting energy expenditure was valid depending on the factors of body weight and gender. It was recommended that this predicted equation would be helpful in directing the training program during walking or running one mile in African American normal weight and overweight adults.

1.2.2 Cross-validation for the equation of Asians

In the cross-validation group, no significant difference was found between the measured values and predicted values calculated by the predicted equation through a dependent t-test. And the coefficients of body weight and gender in the new equation was compared with that of original equation through the Chow test. The coefficients in these two equations were not significantly different. It suggested that these two equations were not difference. And through Figure 4.4, the trends of regression slopes between predicted equations in validation group and in the cross-validation group was similar.

Thus, the cross-validation results supported the validity of predicted equation in Asians. In the practical field, exercise professionals could apply this equation for assessing the energy expenditure during walking or running one mile in Asians.

1.2.3 Cross-validation for the equation of three ethnic groups

Analysis through the dependent t-test showed that there was significant difference between measured and predicted values in cross-validated group. The predicted energy expenditure was underestimated the measured values (106.9 - 103.6 = 3.3 kcal·mile^{-1}). The standard error of estimate (SEE) in predicted equation was 12.5 kcal·mile^{-1}, which was more than 3.3 kcal·mile^{-1}. So it could be acceptable for the estimation error depending on the SEE on the predicted equation. In the Chow test, the result indicated that there was no significant difference between coefficients in these two equations ($p = 0.589$). Figure 4.6 showed that the trends of regression slopes between the predicted equation and cross-validation group equation looked like each other. Also, the standard error bars overlapped.

Therefore, the data coming form cross-validation suggested that there was not enough evidence to reject the predicted equation. And this equation of predicting energy expenditure would be useful for physical training and weight management in Caucasians, African Americans and Asians.

2. Energy expenditure comparison

2.1 Energy expenditure in the African American group

In regard to absolute energy expenditure, normal weight walkers expended less energy corrected for one mile than the runners. In contrast, Loftin et al. (2010) observed no difference between normal weight walkers and runners in primairly a Caucasian sample. Because walking limb posture was more upright than running, muscles generated lower force in walking, which cost less energy (Farley and McMAHON, 1992). Meanwhile, there was no significant difference of absolute energy expenditure between normal weight walkers and overweight walkers. The results of our study confirmed two studies of Treuth et al.(1998) and Ekelund et al.(2002) on normal weight and overweight girls. These authors explained the result by the energy expenditure of moving a larger body mass or high body fat in the overweight/ obese group, by the difference of body acceleration and by movement economy, even though the physical activity was significantly lower in obese girls. Thus, the amount of time spent on physical activity, but not energy expenditure, might be relative to obesity (Ekelund et al., 2002; Treuth et al., 1998).

When energy expenditure was expressed relative to body weight, the energy expenditure difference between normal weight walkers and runners was still significant, and another significant difference between overweight walkers and runners appeared. The similar results were found by Morris, et al. (2014). Body weight had strong relationship with energy expenditure (r= 0.763). The overweight group had significantly higher body weight than runners in the present study. The greater the body mass, the greater the energy cost. The added weight, whether natural or artificial, would lead to an increase of energy expenditure (Loftin et al., 2010). In a study of 11 obese women following vertical banded gastroplasty, the energy expended during physical activity was less than before surgery due to a lower body weight because it was easier to overcome inertia and to overcome friction caused by excess body weight (Öhrström et al., 2001).

When examining energy expenditure related to fat-free mass, which was metabolically active, the energy expenditure in normal weight walker group was lower than runner group and also than overweight group. No difference of fat-free mass was found among the three groups, but the fat mass in normal weight walker group was lower than that in overweight group. Fat mass is relatively metabolically inert during exercise and it can lead to an increase in energy expenditure. In 2009, Woodruff, Hanning and Barr reported that the basal metabolic needs increased when fat mass increased. Further, Welle, Forbes, Statt, Barnard, and Amatruda (1992) suggested that the higher the FFM the higher the basal metabolic rate, which may lead to the increase of total energy expenditure. So the greater fat mass in overweight group might influence the higher basal metabolic rate, and might influence the higher energy expenditure relative to FFM. In a recent cross-sectional analysis including 430 subjects, Drenowata, Jakicic, Blair, and Hand (2015) examined the difference of energy expenditure by intensity, and showed that the overweight participants displayed a higher proportion of energy spent than normal weight peers in sedentary and light activities, but lower than normal weight peers in moderate-to-vigorous physical activity. Therefore, the intensity of physical activity played an important role in energy expenditure.

Energy expenditure in African Americans by gender

The absolute energy expenditure of males was greater than in females, which was also found by Carpenter, et al. (1998). The normal weight walker group expended less energy than the runner group, and this was true in males and females. Furthermore, in females, differences were also noted between normal weight walker and overweight groups. Starling, Toth, Matthews and Poehlman (1998) focused on older African Americans and showed that there was 31% lower energy expended in females compared to males. This result may lead to greater body fatness and to increased cardiovascular risk for African American women. In the current study, when energy expenditure was expressed relative to body weight, this difference disappeared, with both the normal weight walker group and the overweight group less than the runner group whether males or females. Many investigators agreed with the similar energy expenditure relative to BW between genders (Bhambhani and Singh, 1985; Browning et al., 2006; Falls and Humphrey, 1976; Miller and Stamford, 1987; Welle et al., 1992). However, the values of males were less than those of females if the energy expenditure was relative to FFM, similarly as Howley and Glover's (1974) report. For both males and females, the energy expenditure of the normal weight walker group was lower than that of the runner group. However, for females, there was significant difference between normal weight walker group and overweight group. But there was no difference between females and males in energy expenditure relative to FFM suggested by other researchers (Carpenter et al., 1998; Welle et al., 1992).

A number of factors explained the difference by gender. First, body fat or fat percentage explained much of the difference of energy expenditure in gender, even up to 45%

variance of net metabolic rate of walking (Browning et al., 2006). Females had more fat mass than males, especially in hips and thighs, and they had to carry more fat or excess mass during exercise. Also, females had less lean mass which was metabolically active tissue compared to males. Both fat mass and fat-free mass influenced the energy cost. The vertical lift work might be another reason. The reduced lift work with shorter strides length led to an increase of stride frequency, which required more active muscle to work. So more energy was needed, and this part of energy was lost as heat to offset the decreased lift work (Falls and Humphrey, 1976). Howley and Glover (1974) reported that women had greater vertical movement at a slower average running speed. This might explain why females expend more energy than males when energy was expressed relative to FFM. However, through the cinematographic analysis, there was no significance of vertical lift per stride in gender (Bhambhani and Singh, 1985). Thus, further research on vertical locomotion is needed. Also, recovery VO_2 was considered as one reason to explain gender difference. Bhambhani and Singh (1985) suggested that the oxygen recovery accounted for 20.1% of total oxygen cost for females, while 17.3% of total oxygen cost for males. Finally, the physical training level of subjects could influence the results. Miller and Stamford (1987) suggested that, in a female study, the body fat percentage was only 17.8% because all subjects were athletes and well trained. Therefore, the different energy expenditure during physical activity in males and females might be caused by many reasons, such as FFM, fat percentage, vertical lift work, and recovery VO_2.

2.2 Physical activity and energy expenditure in Asians

The prevalence of obesity, an international health concern, is rampant in the whole world, including in Asia. In a review paper which included thirty published scientific manuscripts, Mller, Khoo, and Lambert (2013) reported low levels of physical activity in Asian school age children and adolescents . Nang, et al. (2013) found that the urban Asian population, including Chinese, Malay and Indian in Singapore, spent much amount of time watching television, which was significantly associated with high blood pressure, cholesterol and other cardiovascular and metabolic disease risk factors. Through a survey of 15,390 Taiwanese, half (50.5%) of participants reported no leisure-time physical activity, and among women the percentage was even lower (50.3%) (Wai et al., 2008). Meanwhile, females were more inactive compard to males in South-Asia. Due to the lower proportion of walking women, they were more likely to be obese compared to European women. And over 80% difference of BMI between south Asians and Europeans was explained by low physical activity outside the workplace. Females also had higher prevalence of overweight and obesity in Asian Indians (Chopra et al., 2013; Pomerleau et al., 1999; Ranasinghe et al., 2013). Asian Americans were much less likely to join in leisure-time physical activity, but the foreign-born Asians had the least likelihood, which led to the lower energy expenditure (Kandula and Lauderdale, 2005). Therefore, preventive measures of obesity should be implemented for Asians or Asian women. Knowledge of the energy expenditure is a significant step for weight management and helps fitness professionals to design physical activity programs to avoid obesity.

For absolute energy expenditure, our finding of no significant difference among the three groups (normal weight walkers, overweight walkers, and runners) agreed with previous observations of Caucasians by Loftin, Waddell, Robinson and Owens (2010). Heat production might be one reason for influencing the caloric expenditure. Some physical activity monitors and devices were designed to measure physical activity depending on heat-related sensors (Chowdhury et al., 2017; Szuminsky et al., 2015). What is more, Farley and McMahon (1992) investigated that the limb posture during walking was more upright than the posture in running, so more force generated by muscles was needed to maintain running, which led to running costing more energy than walking. While, when energy expenditure was expressed relative to body weight, the energy of normal weight walker group expended less than runner group, and the energy of overweight group also cost less than runner group. The result of Asian subjects was coincident with African Americans result and supported by Morris, et al. (2014). In the current study, the same result also was showed in males, but the difference between runners and overweight walkers was only found in females. It was possible that the greater body weight of female overweight walkers compared to female runners influenced the energy expenditure relative to body weight. There was a strong relationship between energy expenditure and body weight (r= 0.80) shown in this study. Zalilah et al. (2006) found that the energy expenditure for physical activity was significantly greater for overweight boys and girls compared to normal weight peers in a cross-sectional study with 618 Malaysian adolescents. However, the total energy expenditure per kilogram of body weight in overweight boys and girls was lower than in normal weight subjects. After focusing on FFM, only the difference between normal weight walker group and runner group was shown. There was no difference of absolute energy expenditure or FFM between normal weight walker group and runner group. However, in males, the energy expenditure of normal weight walker group was lower than runner group, which could possibly explain the total result in whole.

For the energy expended in different genders, males expended more absolute energy than females, which agreed with Carpenter, et al. (1998). In the current study, the males had greater body mass than females, thus leading to an increased energy expenditure. More energy was needed to move more mass. There was not a significant difference in males and females if energy expenditure was expressed relative to body weight, which was also noted in the African American samples. Several studies supported this result (Bhambhani and Singh, 1985; Browning et al., 2006; Falls and Humphrey, 1976; Miller and Stamford, 1987; Welle et al., 1992). However, considering FFM, the energy expended by males was significantly lower than that expended by females, as well as by African Americans. This result was explained by the fat-free mass, which in males was significantly higher than in females. The reasons for the difference in males and females, they were possibly the FFM, the fat percentage or fat mass, subjects stride frequency and stride length, recovery VO_2, and subjects training level (discussed in detail in the section on African American).

2.3. Physical characteristics and energy expenditure of Caucasians, African Americans, and

Asians

Obesity is a challenging problem in Caucasians, African Americans and Asians, because it is related to many diseases, such as hypertension, heart disease, diabetes and others. Physical activity was a key factor in total energy expenditure related to obesity. It was reported that the amount of leisure time spent on physical activity was lower in African Americans than in Caucasians (Lovejoy et al., 2001; Washburn et al., 1992), while there was a higher number of inactive African Americans than inactive Caucasians, especially for females (DiPietro and Caspersen, 1991). Comparing the specific physical activity, African Americans had the lowest percentage of leisure-time physical activity, and Asians had the lowest percentage of household-relative activities (Dong et al., 2004). Moreover, all subjects overestimated their energy expenditure through self-reported physical activity, and this trend was greater among African Americans than Caucasians (Walsh et al., 2004). With the different physical activities among ethnic groups, it is necessary to analyze the energy expenditure in order to avoid obesity.

2.3.1 Physical characteristics in Caucasians, African Americans and Asians

Some investigators found that there was no difference between African Americans and Caucasians in body weight, even if body weight accounted for 46% variance of resting energy expenditure, which was the largest amount of variance in resting energy expenditure (Foster et al., 1997; Tershakovec et al., 2002; Weinsier et al., 2000). Meanwhile, the height of Caucasians was significantly greater than African Americans and Asians. It possibly explained the difference of body weight between Caucasians and Asians. Concerning fat mass, African Americans had greater mass than Caucasians and Asians with the same results found in females, but no such difference was seen in males. The females had more fat mass than males as shown in African Americans. It was contrary to what had been reported by Amen-Ra, Velasco-Mondragon, Hossain, and Bronner (2012) and by Foster, Wadden, and Voge (1997) that African Americans fat mass was less than Caucasians, and was also contrary to the investigations that the fat mass was similar between African Americans and Caucasians reported by Tershakovec, Kuppler, Zemel, and Stalling (2002), by Weyer, Snitker, Bogardus, and Ravussin (1999), and by Forman, Miller, Szymanski, and Fernhall (1998). The fat-free mass was less in Asians than in Caucasians and in African Americans, with the same results shown in males and females. The fat mass of males was greater than in females, which was true of African Americans and Asians as well. The data of our study confirmed the study of Wouters-Adriaens and Westerterp (2008) who found that the FFM of Asians was significantly lower than that of Caucasians, and also confirmed the study that there was no difference of FFM between African Americans and Caucasians (Tershakovec et al., 2002). However, a substantial and growing pool of research had established that the FFM of Caucasians was greater than African Americans (Kaplan et al., 1996), or less than African Americans (Carpenter et al., 1998; Forman et al., 1998; Foster et al., 1997; Weyer et al., 1999). Foster, Wadden and Vogt (1997) assessed the body composition by densitometry, which was a methodological limitation in body composition methodology. In their study, the result suggested that the FFM in African Americans was significantly higher than that in Caucasians. However, the African Americans had more total body more mineral and bone density than Caucasians. So this result might overestimate the FFM in African American subjects. After adjusting downward 3% of FFM in African Americans, similar values for FFM between African Americans and Caucasians were observed (Kaplan et al., 1996), which was also found in current study. In order to avoid overestimating FFM, some researchers specified FFM into limb lean mass and truck lean mass. The results demonstrated that African Americans had higher limb lean tissue and lower truck lean tissue compared to Caucasians, even though they had similar FFM totally, which led to the higher proportion of muscle and the lower proportion of metabolically active organ tissue, explaining the reason of lower resting energy expenditure in African Americans (Hunter et al., 2000; Sun et al., 2001; Tershakovec et al., 2002; Weinsier et al., 2000).

2.3.2 Energy expenditure in Caucasians, African Americans and Asians

Interestingly, the majority of previous research exploring energy expenditure focused on resting energy expenditure, while the energy expenditure of physical activity (PAEE) received limited attention. The literature on PAEE in African Americans remained sparse, and relatively little research had been done in PAEE for Asians. Thus, due to the high prevalence of obesity in African Americans compared to Caucasians, it could be hypothesized that PAEE of African Americans should be less than that of Caucasians. The results published by Weiniser, et al. (2000) and Dugas et al. (2009) supports this hypothesis. However, the results of another study (Weyer et al., 1999) showed the opposite result. The result of the current study was consistent with the study of Weyer, Snitker, Bogardus, and Ravussin (1999), which had demonstrated African Americans expended more energy walking one mile than Caucasians during physical activity. It was the same result in males and no difference found in females between Caucasians and African Americans. All the males expended more energy than females, which agreed with the finding by Carpenter (1998). Specifically, the energy expenditure of African Americans was more than that of Asians, and it was true both in males and females. And in female, Caucasians spent more energy than Asians. In the current study, the height of Caucasians was significantly greater than that of African Americans and Asians. This result was supported by the finding of Dugas et al. (2009) who suggested that African Americans were shorter than Caucasians. During walking or running, the increased height contributed to the greater vertical movement and longer stride with decreased stride frequency. So less muscle was involved in physical activity and less energy was needed in Caucasians compared to African Americans (Falls and Humphrey, 1976; Howley and Glover, 1974). Also, the fat mass could influence the basal metabolic needs (Woodruff et al., 2009). The greater fat mass in African Americans caused higher energy expenditure than in Caucasians.

In the current study, when energy expenditure was expressed relative to body weight, the results changed. Body weight was a key factor in energy expenditure, because there was a strong relationship between body weight and energy expenditure (r= 0.775). The body weight of Asian subjects was lowest among three ethnic groups. The added weight, whether natural or artificial, would contribute to an increase of energy expenditure (Loftin et al., 2010). Thus, the lower body weight in Asians compare to African Americans and Caucasians could explain the lower energy expenditure in Asians than the other two counterparts.

Considering the fat-free mass during energy expenditure, Caucasians was the lowest compared to African Americans and Asians. A growing body of research indicated that the muscle mass in arms and legs was higher in African Americans compared to Caucasian counterpart with the similar total fat-free mass (Hunter et al., 2000; Sun et al., 2001; Tershakovec et al., 2002; Weinsier et al., 2000). During physical activity, the higher portion of limb muscle tissue would produce more energy to support exercise, which led to the higher energy expenditure of African Americans.

In a review paper, Ceaser and Hunter (2015) showed that African Americans had reduced levels of hemoglobin concentration than Caucasians. During exercise, hemoglobin is important in oxygen transportation from respiratory organs to working muscles. Ceaser and Hunter noted that African Americans tended to have more type II muscle fibers than Caucasians, which may lead to the reduced endurance and increased fatigue. Furthermore, the reduced hemoglobin concentration and more type II muscle fibers influenced the lower aerobic capacity in African Americans. All these factors may have influenced difference of physical activity energy expenditure in African Americans. Hunter et al. (2004) reported that Caucasian women spent more time in physical activity than African Americans. Thus, the physical activity in African Americans was less than in Caucasians, which explained up to 75% of variance in total energy expenditure (Kushner et al., 1995), even if the physical activity energy expenditure in African American was higher than Caucasians. Meanwhile, the deficit of lower resting energy expenditure in African Americans should be compensated by increasing physical activity. Therefore, the total daily energy expenditure, the left sum of daily physical activity and physical activity energy expenditure except resting energy expenditure and thermic effect, has been shown to be lower in African Americans than in Caucasians, which might lead to obesity in African Americans at last.

In the current study, some parts of the results were different from other investigations. To explain these differences in results, some possible explanations might be differences in the designs of exercise experiments. The energy expenditure of the current study was measured on the treadmill during walking or running through an indirect method, which was a different testing method from other studies. Also, the sample size might be one reason for different results. Additional research could amplify the number of participants to test the results.

CHAPTER 6

CONCLUSIONS

In this study, specific predicted energy expenditure equations were developed for African Americans, Asians, and the combined three ethnic groups including Caucasians. And through cross-validation testing, it showed that these equations were more accurate than any of currently available equations. So, we recommend to use these equations during walking or running one mile for normal weight and overweight adults. However, due to the variance in different environments, the operators should consider the specific characteristics of subjects in clinical use.

Also, this study compared physical characteristics and energy expenditure. The absolute energy expenditure, energy expenditure relative to body weight and energy expenditure relative to FFM were compared among normal weight walkers, overweight walkers and runner groups in African Americans, Asians and a combined three ethnic groups including Caucasians.

Significance

To my knowledge, it is the first time to develop equations for predicting energy expenditure during walking and running one mile at preferred pace in African American and Asian normal weight and overweight adults. Meanwhile, it is also the first time to develop energy expenditure predictive equation combined African Americans, Asians and Caucasians through 224 participants.

Future Research

First, this study examined the absolute energy expenditure during walking or running, which may partly explain the prevalence of obesity in African Americans compared with

Caucasians. However, the total daily energy expenditure may explain the reason of obesity overall. So the total daily energy expenditure will be tested to provide enough support for lower total energy expenditure per day contributing to obesity in African Americans in the future studies.

Also, the vertical locomotion, such as stride length or step frequency, could influence the difference of energy expenditure in different genders. In future work, these factors could be measured to examine any gender related differences.

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