VALIDATION OF THE SENSEWEAR PRO 2 ARMBAND TO ASSESS ENERGY EXPENDITURE OF ADOLESCENTS DURING VARIOUS MODES OF ACTIVITY

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VALIDATION OF THE SENSEWEAR PRO2 ARMBAND CALORIMETER TO ASSESS ENERGY EXPENDITURE OF ADOLESCENTS DURING VARIOUS MODES OF ACTIVITY

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The primary purpose of this investigation was to examine the validity of the SenseWear® Pro 2 Armband (SAB) to assess energy expenditure during various modes of physical activity in adolescents. It was hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SAB and the criterion respiratory metabolic system (RMS) when examined for female and male subjects. Twenty-four healthy adolescents completed both the cycle ergometer and treadmill exercise protocols.

The primary findings of this investigation were the SAB significantly underestimated energy expenditure during cycle ergometer exercise at the low (1.53 $\pm$ 0.60 $kcal \cdot min^{-1}$; $P<0.001$) and moderate (2.48 $\pm$ 0.95 $kcal \cdot min^{-1}$; $P<0.001$) intensities and for total energy expenditure (19.11 $\pm$ 7.43 kcal; $P<0.001$) in both the female and male subjects. In the treadmill exercise, there were no significant differences between measures of energy expenditure during treadmill walking at 3.0 mph, 0% incline in female and male subjects. However, the SAB significantly underestimated measures of energy expenditure at 4.0 mph, 0% grade (0.86 $\pm$ 0.84 $kcal \cdot min^{-1}$; $P<0.001$); 4.0 mph, 5% grade (2.13 $\pm$ 1.40 $kcal \cdot min^{-1}$; $P<0.001$); 4.5 mph, 5% grade (2.97 $\pm$ 1.56

kcal·min^{-1}; $P<0.001$) and for total energy expenditure (23.66 ± 14.92 kcal; $P<0.001$) during treadmill exercise in female and male subjects.

Possible mechanisms underlying the underestimation of energy expenditure by the SAB are complex but may include: the use of generalized exercise algorithms to predict all types of physical activity; possible disproportionate reliance on the two-axis accelerometer during non-weight bearing and graded exercises; the delay in body heat transfer to the skin; and the inability to account for variability in walking gait, lean body mass and fat mass. All of these factors impact on the accuracy of the SAB to accurately estimate energy expenditure. This is the first study to examine the accuracy of the SAB in adolescent subjects and is an important first step in validating SAB technology in adolescents.

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Dr. Ray Burdett
Dr. Fred Goss
Dr. John Jakicic
Dr Betsy Nagel-Stilley
Dr. Bob Robertson
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CHAPTER 1

INTRODUCTION, PROBLEM, HYPOTHESIS

1.1. INTRODUCTION

The purpose of this study was to examine the validity of the SenseWear® Pro 2 Armband to assess energy expenditure during various modes of physical activity in adolescents. The instrument was designed to monitor and record continuous physiological data such as heart rate, energy expenditure, activity level, and sleep/wake states in the free-living environment [1]. A physical activity measuring device that accurately estimates physical activity and energy expenditure in children in their free-living environment provides clinicians and researchers with important information to determine energy balance. In an era where the childhood obesity rate is rapidly increasing and participation in physical activity is declining, accurate measurements of physical activity duration, intensity and frequency as well as associated energy expenditure, will provide critical information upon which to develop dietary and exercise interventions. This information will help determine the proper physical activity guidelines and exercise prescriptions for children and adolescents that will optimize growth, health, and well-being.

1.2. BODYMEDIA SENSEWEAR® PRO 2 ARMBAND

The BodyMedia SenseWear® Pro 2 Armband is a wireless, wearable body monitor that collects and analyzes physiological and lifestyle data to determine energy expenditure, activity levels and sleep/wake states. Worn on the back of the right upper arm (Triceps), the SenseWear® Pro 2 Armband has a unique array of biometric sensors that include a two-axis accelerometer, heat flux sensor, skin temperature sensor, near-body ambient temperature sensor and galvanic skin response sensor (see Figure 1). It also has a built-in transceiver module that enables wireless two-way communications between the SenseWear® Pro 2 Armband and other third-party digital devices such as heart rate monitors, blood pressure devices, pulse oximeter, body weight scales, treadmills, etc. These multiple sensors can sample a number of different physiological parameters simultaneously over time. The physiologic information collected by these sensors along with personalized body measurements including gender, age, height and weight are processed using SenseWear's algorithms to provide estimations of energy expenditure for many different types of activity over a 24-hour period [1].

Figure 1 Body Media SenseWear Pro 2 Armband

The BodyMedia's InnerView™ Research Software Version 4.0.610 was used to retrieve and to save physiological and lifestyle data from the SenseWear® Pro 2 Armband. Data was exported for further analysis. A summary page (Figure 2) provides information on total energy expenditure, number of steps, minutes of physical activity, amount of time lying down and duration of sleep, as well as the wearer's descriptive parameters (age, height, weight, gender, handedness and smoking preference) and date of the data period. In addition, the software allows users to customize data collection by configuring the sampling rates and duration of the 24 data collection channels on the Armband to meet their application needs.

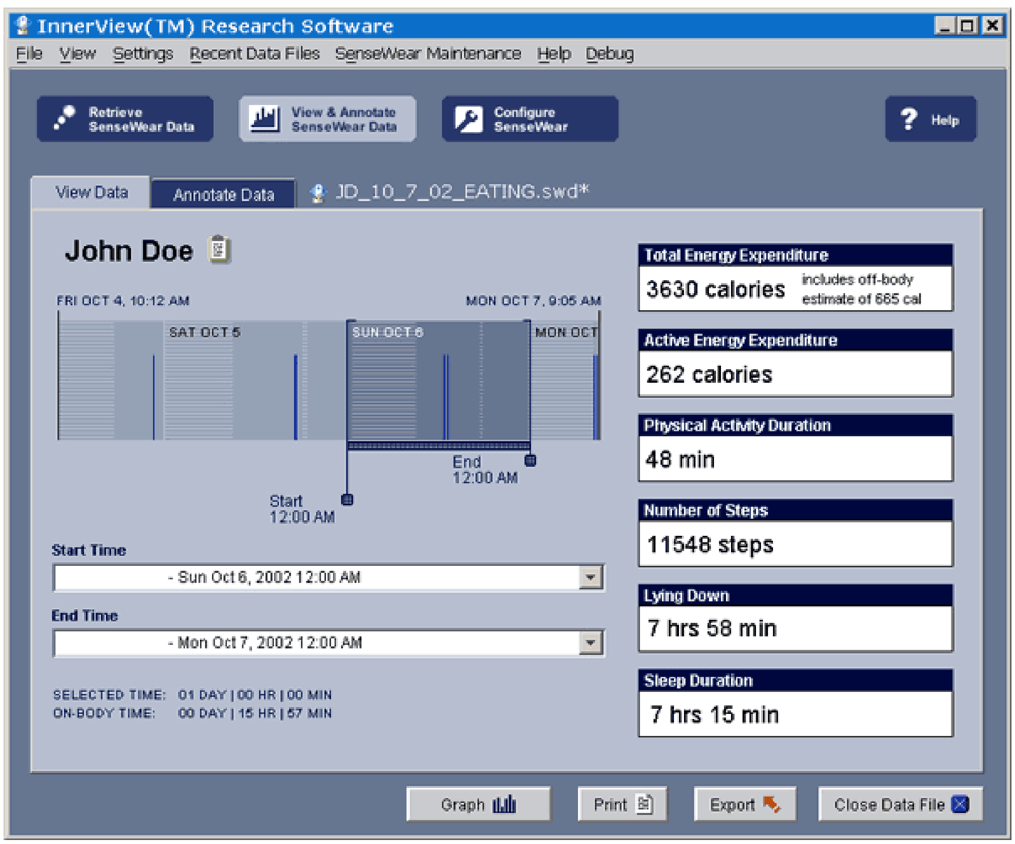


Figure 2 InnerView Research Software Summary Data Page

1.3. MEASUREMENT PROCEDURES: SENSEWEAR® PRO 2 ARMBAND

The combined input from the various physiological sensors and accelerometer makes the BodyMedia SenseWear® Pro 2 Armband unique in its ability to estimate energy expenditure. In contrast to pedometers and accelerometers that only record information on body movement, the SenseWear® Pro 2 Armband gathers additional data about heat produced by the body and surrounding environment to aid in the calculation of energy expenditure [2]. The heat flux and temperature sensors allow the armband to measure heat produced by the body as a result of resting metabolism as well as all forms of physical activity including weight bearing, non-weight bearing, upper and lower body movement. In addition, it is proposed to be able to detect the increased energy expenditure associated with manual transport of a payload and changes in grade and intensity of locomotion. The option to monitor heart rate provides further information on cardiovascular responses to changes in frequency, intensity, and duration of physical activity patterns. The physiologic data collected by all of the sensors is exported to the InnerView Software and combined with the individuals body parameters (previously described) and is processed through a series of algorithms to provide estimations of energy expenditure.

1.4. PHYSICAL ACTIVITY MONITORS

Assessment of the quantity and quality of daily physical activity is an essential measurement in physical activity research. Epidemiological researchers continue to search for valid, reliable, objective measures to assess physical activity and energy expenditure in free-living individuals. "Methods for measuring human energy expenditure are either precise but very restrictive—and thus limited to use over a short period of time—or they are less restrictive and usable over long periods but are rather imprecise [3]"

To date, a number of physical activity monitors have been validated as tools to measure physical activity and/or energy expenditure [4-7]. Unfortunately, the accurate assessment of physical activity energy expenditure, especially in the field setting, has proven problematic. Investigators have relied on less precise measures, such as self-report methods (i.e. physical activity interviews, recall surveys and questionnaires), motion assessment devices (i.e. pedometers, accelerometers), and physiological data (i.e. heart rate and body temperature). The more precise measures such as indirect calorimetry (IC) and doubly labeled water (DLW) are considered the criterion variables for assessing energy expenditure in adults and children. Inherent in all these techniques are limitations that restrict their use in measuring energy expenditure and physical activity levels especially in the free-living environment.

Devices such as pedometers, accelerometers and heart rate monitors have become increasingly popular as measurement tools to assess physical activity and estimate energy expenditure. These devices reduce the subjectivity inherent in survey methods; can be used with large groups of individuals to assess physical activity patterns; and are relatively inexpensive. Unfortunately, even though these devices provide fairly accurate measures of body movement, it has been difficult to validate their accuracy in calculating energy expenditure over a 24-hour period.

Although IC and DLW are the most accurate methods to determine energy expenditure of physical activity, these techniques are expensive and require laboratory instruments and analysis, making them less desirable to use in large population-based free-living studies. In addition, neither of these methods can differentiate between types and patterns of physical activity. Never the less, both IC and DLW are accepted as validation tools for assessing the accuracy of other physical activity monitors to estimate energy expenditure.

To improve the accuracy and validity in assessing physical activity energy expenditure, a number of different measurement systems have been combined. The most frequently employed is a combination of heart rate monitoring and accelerometry. Preliminarily investigations report improved precision in measuring physical activity energy expenditure using these combined measurement systems [3, 8, 9].

The SenseWear® Pro 2 Armband also uses the combination measurement system to calculate energy expenditure. Preliminary experimental evidence has demonstrated that the SenseWear® Pro 2 Armband is accurate in predicting physical activity energy expenditure of adults in the laboratory setting [10]. In addition, it has shown that the instrument is easy to use, capable of providing information about the energy expenditure of physical activity over time as well as frequency, duration, and intensity of single exercise bouts [11]. The data generated by the SenseWear® Pro 2 Armband provide information on total energy expenditure, active energy expenditure, physical activity duration, resting energy expenditure, steps, lying down duration, and sleep duration. A noninvasive instrument such as the SenseWear® Pro 2 Armband that can be used to study the relation between the energy expenditure of physical activity and health in children could have great value in exercise research and public health intervention programs.

1.5. STATEMENT OF THE PROBLEM

The purpose of this investigation was to:

a. To validate the accuracy of the SenseWear® Pro 2 Armband in measuring energy expenditure of healthy children ages 12-17 years while walking/running on a treadmill and pedaling on a cycle ergometer.

b. To examine whether the SenseWear® Pro 2 Armband energy expenditure measurements during treadmill and cycle ergometer exercise are valid for separate and combined groups of male and female adolescents.

1.6. HYPOTHESES

It was hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SenseWear® Pro 2 Armband and criterion respiratory-metabolic procedures when compared separately for the female and male sample sub-sets. It was also hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SenseWear® Pro 2 Armband and respiratory-metabolic procedures for the combined group of male and female adolescents. These findings would provide validation of the SenseWear® Pro 2 Armband to estimate energy expenditure and physical activity levels in normal weight children ages 12-17 years participating in treadmill and cycle ergometer exercise.

2. CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

The purpose of this study was to examine the validity of the SenseWear® Pro 2 Armband to assess energy expenditure during various modes of physical activity in adolescents. The respiratory-metabolic system served as the criterion instrument by which the SenseWear® Pro 2 Armband was evaluated to assess energy expenditure in the laboratory setting. To date, a number of different physical activity monitors have been validated as tools to measure physical activity and/or energy expenditure in the laboratory setting [4, 6, 7, 12]. Unfortunately, the accurate assessment of physical activity energy expenditure, especially in the field setting, has proven problematic. Investigators have relied on comparatively less precise measures of physical activity, such as self-report methods (i.e. physical activity interviews, recall surveys and questionnaires), motion assessment devices (i.e. pedometers, accelerometers), and physiological data (i.e. heart rate and body temperature). The more precise measures such as indirect calorimetry (IC) and doubly labeled water (DLW) are considered the criterion variables for assessing energy expenditure in adults and children. Inherent in all these techniques are limitations that restrict their use in measuring energy expenditure and physical activity levels in the free-living environment. The following literature examines the validity of a physical activity monitor to assess the energy expenditure of adolescents.

2.1.1. PHYSICAL ACTIVITY IN CHILDREN

Many children are less physically active than recommended and physical activity declines rapidly during adolescence. Physical activity is defined as any body movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level [13]. Physical activity can be planned or incidental. The Centers for Disease Control and Prevention (CDC) reports nearly half of all American youths 12-21 years are not vigorously active on a regular basis and approximately 14% of young people report no recent physical activity [14, 15]. Data from national and international surveys suggest an alarming decrease in the prevalence of physical activity participation in older children [13]. The decline in physical activity with age may be the most consistent finding in physical activity epidemiology [16]. The Healthy People 2010 report indicates that participation in all types of physical activity strikingly declines as age or grade in school increases. In 1991, 42% of students in grades ninth through twelfth were physically active for 30 minutes or longer on 5 or more days per week. By 1999 the percentage of physically active high school students had dropped to 27%. Overall, age is inversely associated with physical activity in studies of children [16], adolescents, US adults [17], and adults in international studies [16, 18].

2.1.2. Sedentary Activities

Changing lifestyles of American children have decreased their opportunity to be physically active. Attractive sedentary alternatives such as realty TV shows, interactive video games and instant conversation and exposure to the world via computers have replaced, in part the amount of time children spend in physical activity. Results from the Third National Health and Nutrition Examination Survey (NHANES III) indicate that more than one quarter of children in the United States spend 4 hours or more per day watching television. More recently the

Centers for Disease Control and Prevention Youth Risk Behavior Surveillance 2001 reported that 38.3% of adolescents in grades 9-12th watched 3 or more hours of television during an average school day. Next to sleeping, television watching occupies the greatest amount of leisure time during childhood. Researchers have found that television viewing is correlated with an increase in pediatric obesity, perhaps because it is accompanied by between meal snacking and consumption of high calorie, high fat foods advertised on television. Such sedentary activities require minimal energy in excess of resting energy expenditure (REE), reduce time spent in energy demanding activity, and promote increased dietary energy intake [19].

Another sedentary alternative competing with physical activity is playing on the computer. Compared to television and video games though, children spend less time per day using computers. Funk surveyed seventh and eighth grade boys and girls from a middle-class school to evaluate the impact of video games on leisure time activity in children [20]. The survey revealed that 29% of boys and 15% of girls play video games between 3 to 6 hours per week, and 23% of boys and 6% of girls spend more than 6 hours per week playing video games.

In general, the hours adolescents spend in sedentary activities are on the rise, causing hours spent engaged in physical activity to decline, resulting in lower dietary energy expenditure and higher body weights. An accurate physical activity monitor that measures energy expenditure of physical activity in a free-living setting could be used to identify those children who are physically active. Once identified these children can be stratified and studied to explain predictors, antecedents, and determinants of this behavior [13].

2.1.3. Childhood Overweight Rates

In correspondence with the increased time spent in sedentary activities is the dramatic increase in childhood and adolescent overweight rates. There has been a 50% increase in the prevalence of children with a body mass index (BMI) between the 85^{th} and 95^{th} percentiles, placing them in the category of "at risk for overweight". More alarming is the increase in prevalence by 100 % of those children with a BMI >95^{th} percentile, classifying them as overweight [21, 22] More specifically with regard to age, the National Health and Nutrition Examination Survey (NHANES) 1999-2000 reported 15% of children aged 6-11 years and 15% of adolescents aged 12-19 years in the United States were overweight. This means that the percent of children in the United States that are overweight has nearly doubled, and the percent of overweight adolescents has almost tripled in the last two decades [23].

2.1.4. Chronic Positive Energy Balance

The increasing prevalence of obesity in American children suggests that they experience a chronic positive energy balance. This implies poor coupling between dietary energy intake and energy expenditure. The contribution that each of these two factors plays in the etiology and development of overweight and obesity remains unclear [24]. Epstein et al. examined the effect that changing sedentary behavior had on energy intake and/or physical activity level [19]. Results indicated that activity energy expenditure decreased by 21% when sedentary behaviors were increased.

This decrease in daily active energy expenditure translated into an excess of 350 kilocalories (kcal) per day. Of this excess 350 kcals per day, 250 kcal came from an increase in dietary energy intake and a 100 kcal came from a decrease in energy expenditure. The positive energy balance caused by increasing caloric intake and decreasing energy expenditure of 350 calories per day would result in a body weight gain of 0.7 pounds per week or 36.4 pounds per year. In a similar study, Boreham et al. reported that children expend approximately 600 kcals less per day than their counterparts did 50 years ago [25]. Without reducing caloric intake, this decrease in energy expenditure would produce a 60-pound increase in body weight over one year. Fortunately, children are not gaining weight at this high rate. However these findings do raise more questions about the relative contribution of energy expenditure and energy intake in the obesity equation. A physical activity monitor that accurately measures energy expenditure in the free living environment would be very helpful in clarifying the contribution energy expenditure plays in the energy balance equation.

2.1.5. Decline in Cardiorespiratory Fitness

Not only has spending more time in sedentary activities contributed to increasing body weight but also to the decline in cardiorespiratory fitness observed in children and adolescents. Ahmad et al. examined whether the reduced physical activity levels observed in contemporary white American children resulted in decreased fitness levels and performance on a standardized exercise test [26]. Investigators tested a cohort of healthy nonobese 15 to 18 year old white American boys and girls on the treadmill using the Bruce protocol. Current data were compared to data from a retrospective analysis of Bruce treadmill exercise tests preformed from March 1991 to November 2000, resulting in a total of 347 individual subjects [27]. Exercise endurance times were lower in all age groups for the contemporary subjects compared with earlier published data using the Bruce treadmill protocol, despite physiologic evidence of maximal effort in both groups. These observed decreases in endurance capacity raise the possibility that cardiovascular conditioning is comparatively lower in contemporary white American children. Research evidence that children have become less active to the point where these low levels of daily energy expenditure seriously damages their current and future health has been difficult to establish.

2.1.6. Cardiovascular Risk Factors in Adolescents

It has been hypothesized that the relation between physical fitness and cardiovascular risk factors in children is similar to that in adults [28]. In studies conducted on adults, regular physical activity has been shown to have a positive effect in reducing cardiovascular risk factors such as body fatness (including abdominal fat), blood pressure, lipid and lipoprotein levels and insulin insensitivity. This relation has been more difficult to identify in children. The effects of physical activity on cardiovascular risk profile are less clear, and overall the results are not strong, possibly because the prevalence of abnormality is low and the absolute range of risk factor is narrow in children.

Current research findings however, are beginning to substantiate the relation between regular physical activity and physical fitness and health status in children. Investigators are finding that those children who perform better on standardized fitness tests, and thus in general are more physically active on a routine basis, have more favorable body composition and lipid profiles. In a study analyzing the relation between physical activity and antecedent risk factors for coronary heart disease, Boreham et al. found that higher levels of physical activity were associated with more favorable risk profiles [29]. More specifically, for boys 12 and 15 years old, physical activity was significantly related to healthy risk profiles for blood pressure and cardiorespiratory fitness. For the 15-year-old boys, physical activity was also related to a lower ratio of total cholesterol to high density lipoprotein cholesterol (TC:HDL). Results were slightly different for girls. Physical activity was unrelated to any of the biological risk factors for CHD. On the other hand sports participation was significantly related to cardiorespiratory fitness for both 12 and 15 year old girls and body fatness for 15-year-old girls.

Similarly, DuRant et al. found that higher levels of cardiorespiratory fitness and lower levels of body fatness were associated with healthier serum lipid and lipoprotein levels in 4 and 5 year old black and white children [30]. In a longitudinal study conducted by Twisk et al., physical activity was significantly related to high density lipoprotein (HDL) levels, inversely related to both TC:HDL ratio and the sum of four skinfold measures [31]. Results from studies such as these suggest that more active children are leaner and display a healthier cardiovascular profile. Use of a physical activity monitor that accurately measures energy expenditure and physical activity duration, intensity, and frequency, will help investigators identify the dose-response relation between physical activity and health.

The optimal amount and type of exercise for children and adolescents has not been precisely defined but should be individualized based on maturity level, medical status, skill level, and prior exercise experiences [14]. Several health organizations encourage all persons 6 years of age and older to accumulate at least 30 minutes of moderate-intensity physical activity on most and preferably all days of the week [14]. The Dietary Guidelines for Americans 2000 and the new Dietary Reference Intakes 2002 recommend that children get at least 60 minutes of physical activity each day and limit inactive forms of play such as TV watching and computer games. An accurate physical activity monitor that measures the time and energy expenditure of physical activity will help scientists to determine the proper physical activity guidelines and exercise prescriptions for children and adolescents that will optimize growth, health, and well-being.

2.2. PHYSICAL ACTIVITY MONITORS

2.2.1. Overview

Research has relied on various physical activity monitors such as motion sensors, heart rate monitoring, and doubly labeled water to answer important questions about the relation between physical activity and health in children. Although doubly labeled water is the most accurate of the three methods in determining energy expenditure, it is expensive, requires laboratory analysis, and does not differentiate between types and patterns of physical activity. Motion sensors and heart rate monitors are problematic because they are inaccurate in estimating energy expenditure.

The SenseWear® Pro 2 Armband has shown promising results with respect to estimating the energy expenditure of physical activity in adults [10]. The SenseWear® Pro 2 Armband is easy to use and is relatively inexpensive. The data generated provide information on total energy expenditure, active energy expenditure, physical activity duration, resting energy expenditure, steps, and duration of lying down and sleep. This noninvasive method to study the relation between physical activity and health could have great potential in health-fitness and public health research involving children.

2.2.2. Validation Criterion Measures

Investigations have used a variety of criterion measures to examine the validity of physical activity monitors. The accepted criterion standards, or primary measures for assessing physical activity in adults and children are direct observation, doubly labeled water and indirect calorimetry. Doubly labeled water is recognized as the criterion measure for field evaluations of energy expenditure. Secondary measures include heart rate, pedometers and accelerometers. Validating a secondary measure by another secondary measure provides little insight to the instruments' true validity. For this reason only the results from studies that validated a secondary measure against a primary measure were included in this review [32].

2.2.3. Accelerometers

Accelerometers "use piezoelectric transducers and microprocessors that convert recorded accelerations to a quantifiable digital signal referred to as counts" [32]. The theoretical basis underlying the use of an accelerometer to assess the total amount of physical activity is that acceleration is directly proportional to muscular forces required for movement and therefore, is related to energy expenditure [5]. The first generation, or uniaxial accelerometers, measure movement in one plane, the vertical plane. The newer generation, triaxial accelerometers, measure movement in three dimensions (mediolateral, anteroposterior, and vertical) as well as the vector magnitude.

Uniaxial Accelerometers. Technological advances in uniaxial accelerometers have made them a useful device for measuring physical activity. These monitors are small, unobtrusive instruments with a memory capacity for monitoring and storing temporal patterns of activity, as well as measuring intensity and quantity of movement. The biggest obstacle involving these instruments, however is that not all activity is reflected in acceleration and deceleration. Therefore, the monitors would not be accurate in estimating total daily energy expenditure. Thus reports on validity of using uniaxial accelerometers to estimate energy expenditure vary greatly.

The Caltrac and The Computer Science and Applications, Inc (CSA) instruments were two of the first and most widely studied uniaxial accelerometers in the research setting. In controlled laboratory treadmill experiments, walking counts from the Caltrac have correlated highly, r=0.82 [33] and r=0.88 [34] with oxygen consumption (VO_2). Maliszewski reported no significant differences between measured oxygen consumption and estimated energy expenditure by Caltrac in children during treadmill walking at speeds ranging from 3.35 to 6.7 $km.hr^{-1}$.

Trost et al. [35] conducted an experiment to quantify energy expenditure in 10-14 year old children during walking and running on the treadmill using CSA counts and oxygen consumption as the criterion measure. The correlation between actual (derived from oxygen consumption measures) and predicted mean energy expenditure (estimated from a regression equation based on counts from CSA) at each of three treadmill speeds (3, 4, and 6 mph) was r=0.85, r=0.62 and r=0.81 respectively.

When treadmill grade is increased or non-locomotor activities such as cycling and weight lifting are tested, the uniaxial accelerometers have either underestimated or overestimated caloric expenditure. Bray et al. found the Caltrac underestimated energy expenditure by approximately 30% of an 8-hour daily activity session consisting of sedentary activities (eating, reading, watching television, and listening to music) and two 20-minute cycle ergometer bouts [36]. They attributed the large estimation error to two factors: 1) energy expenditure during cycle ergometer exercise was included in walking energy expenditure and this decreased the overall accuracy and 2) the Caltrac does not reflect excess post-exercise energy expenditure, because subjects were usually sitting or resting in a lying down position after exercise.

In a study comparing energy expenditure derived from Caltrac counts and daily total energy expenditure (TEE) derived from doubly labeled water, Johnson et al. concluded that the Caltrac was not a meaningful predictor of energy expenditure [37]. The caloric estimates (956 kcals per day) of energy expended in physical activity derived from Caltrac were significantly higher when compared to measured active energy expenditure (469 kcal per day) in children participating in a free-living setting. Active energy expenditure was calculated by subtracting postprandial resting metabolic rate measured via indirect calorimetry from daily TEE. Since the uniaxial accelerometers only measure movement in a single plane, this limits their ability to detect the wide variety of movements typical of children, especially in studies conducted outside the laboratory setting.

Triaxial Accelerometers. The development of the three-dimensional accelerometer, or triaxial accelerometer, was intended to improve the accuracy of energy expenditure estimated by a motion sensor. The triaxial accelerometer measures physical activity counts in three planes (vertical, horizontal, and mediolateral) as well as vector magnitude over a specified time interval. The vector magnitude is a summary measure of the accelerations recorded in all three planes. It is calculated as the square root of the sum squared activity counts in each vector [38]. The Tritrac is the most commonly used triaxial accelerometer. Total and activity energy expenditure in kilocalories is determined using a prediction equation to estimate basal metabolic rate according to age, height, body weight, and gender.

Theoretically, the three-dimensional properties of the Tritrac would make it better suited to assess more sporadic lifestyle activity. While this argument has strong intuitive appeal, field and laboratory-based studies testing the relative validity of accelerometers have been equivocal [39]. Hendelman et al. observed a high correlation (r=0.89) between Tritrac vector magnitude and measured VO_2 for over ground walking [40]. However, when the two methods were compared for walking and various household and recreational activities, the correlation decreased to r=0.62. A 32.1-53.1% underestimation of energy expenditure from the Tritrac was observed over all the activities studied.

In a similar study, Welk et al. examined the validity of three activity monitors under both laboratory and field conditions [41]. Three different treadmill speeds and six different lifestyle activities (sweeping, vacuuming, stacking, raking, mowing, and shoveling) were examined to evaluate the validity of the monitors. Oxygen consumption determined by indirect calorimetry served as the criterion measure. A higher correlation (r=0.86) was found between the monitors and measured VO_2 for the treadmill tests compared to the lifestyle activities (r=0.55).

Very few research studies have been conducted validating triaxial accelerometers using a primary criterion measure in children. Eston et al. compared the accuracy of heart rate monitoring, pedometry, triaxial accelerometry, and uniaxial accelerometry for estimating oxygen consumption during typical children's activities (playing catch, playing hopscotch, and sitting coloring) [4]. It was found that the best single measurement of energy expenditure was the Tritrac vector magnitude with a correlation of r=0.83 between accelerometer counts and measured scaled oxygen consumption (sVO_{2}). Allometrically scaled oxygen consumption is defined as oxygen uptake expressed as a ratio of body mass raised to the power of 0.75. In examining the children's activities separately however, there was a clear tendency for the Tritrac to underestimate energy expenditure as exercise intensity increased. When comparing all of the devices tested though, Tritrac provided the best overall measurement of physical activity.

Welk et al. compared data from the Tritrac and a heart rate monitor to observational data using the Children's Activity Record System (CARS) for two time periods (40-minute normal classroom period and a 30-minute physical education class). The CARS uses five different activity categories to classify the subjects level of physical activity [42]. The average activity code over each minute is calculated and represents the activity level for that minute. The convergent validity of the two monitoring devices was determined independently using correlational analyses and in combination using multiple regression analyses for each time period [43]. The Tritrac vector magnitude correlated significantly higher (r=0.70) than heart rate (r=0.49) for the normal classroom time period. However, when the physical education class was compared, heart rate had a slightly stronger correlation (r=0.79) than the Tritrac vector magnitude (r=0.77). Overall, investigators determined that the Tritrac provides a valid assessment of physical activity under both classroom and physical activity conditions, however, heart rate proved valid only during the active time period.

Overall, the triaxial accelerometers provide a valid measure of physical activity [44], but their estimations of energy expenditure are less accurate. In general, these monitors overestimate energy expenditure for activities with a small force:displacement ratio such as jumping, running; and underestimate energy expenditure for activities with large force:displacement ratio such as stair climbing, knee bends [3]. Their use in accurately estimating energy expenditure during physical activity is also limited by the mode of exercise (non-weight bearing activities such as cycling and static exercises such as weight lifting), by activities involving upper body movement, by carrying a load, and by changes in surface and terrain [45].

Another problem inherent in this technique is the difficulty converting accelerometer outputs, or counts, to units of energy expenditure. Algorithms or "count cutoffs" have been derived to convert accelerometer counts to units of energy expenditure, but the predictive validity of these equations in field settings has not been determined [32]. These monitors also lack valid population specific regression equations, which increase error in the calculations.

An additional problem, related to the use of prediction equations, such as used in the triaxial accelerometers, is that they assume steady-state exercise over a one-minute interval. Consequently, if a child alternates between vigorous physical activity and rest within a given minute (typical child play), the accumulation of counts for that minute will reflect only the average activity level during that period [39]. Because this device does not differentiate between intensities of physical activity, it compromises the accuracy of the absolute energy expenditure estimations.

Despite these limitations, accelerometers have numerous advantages making them a useful physical activity-measuring device. Accelerometers provide an objective, portable, re-usable tool for assessing physical activity in large-scale epidemiological studies. They are small, easy to use, and provide objective measures of activity across the full range of the activity continuum. Many of these devices have the ability to store movement data for long periods of time and feature interval based time sampling. These features make them well suited for objective and detailed records of physical activity for behavioral and epidemiologic research.

2.2.4. Heart Rate (HR) Monitoring

The assumption underpinning HR monitoring as a measure of energy expenditure during physical activity is that a linear relation exists between heart rate and oxygen consumption during steady state exercise [5]. This relation, however, is most accurate for moderate intensity exercise in the heart rate range of 110-150 beats per minute (bpm). It is not as valid at lower (<110 bpm) and higher (>150 bpm) exercise intensities [4, 46, 47]. Eston et al. examined the validity of HR monitoring in predicting the energy expenditure of physical activity in children [4]. Heart rate was monitored and compared to allometrically scaled oxygen consumption (sVO2) for a variety of exercises (treadmill walking and running) and typical children's play activities (hopscotch, catch, and coloring). Across all seven activities, HR was moderately correlated with sVO2 (r =0.80). The mean error was the highest for sitting and coloring, followed by catching, and the 8 and 10 km/h treadmill runs respectively. The mean error was the lowest for hopscotch and the 4 km/h treadmill walk.

Similarly Welk et al. validated the use of HR to estimate physical activity energy expenditure at low and high HR activities [43]. It was concluded that HR monitoring provided a valid measure of physical activity during periods of increased activity (physical activity class) but not during periods of relative inactivity (classroom activity). The within subject correlation between HR and observed physical activity were similar during physical education class (r=0.79) but were substantially lower during classroom activities (r=0.49).

There are many factors that raise HR while having little effect on the oxygen requirement of the physical work. These include: emotional stress, fatigue, hydration status, food intake, ambient temperature, humidity, body position, posture, active muscle group, type of muscle contraction, gender, cardiorespiratory fitness, body size, and body composition [48]. For example, high ambient temperatures, high humidity, and emotional stress will cause an increase in heart rate without a significant rise in oxygen consumption during dynamic exercise. This is one factor that limits the use of HR to predict energy expenditure of physical activity.

With respect to children, the physical fitness levels are also a limiting factor when HR monitoring is used to assess physical activity. A higher aerobically fit child has a larger stroke volume and hence a lower heart rate for any given activity. Mean daily heart rates may therefore, be more representative of children's physical fitness than their activity level [4, 7, 39].

Another problem when HR is used to predict energy expenditure is that HR response tends to lag momentarily behind changes in movement. It is highly unlikely that laboratory modeled HR-VO_2 relations can capture the HR-VO_2 dynamics associated with the typically rapid changes in free-living activity patterns of children. In addition, the return of heart rate to baseline also lags behind the return of oxygen uptake to baseline during recovery after physical activity. Therefore, the use of exercise recovery HR results in an overestimation of energy expenditure [5]. Children's physical activity is highly transitory. The relative delay in heart rate response to changes in movement suggests that heart rate monitors may mask potential energy cost information. All of these factors have led investigators to question the validity of HR monitoring to accurately predict energy expenditure.

Emons et al. reported an overestimation by 10.4% and 12.3% when comparing energy expenditure derived heart rates to energy expenditure actually measured during a 1 day stay in a total body calorimeter and a 2-week period of doubly labeled water assessment, respectively [49]. It was also found that the predicted energy expenditure of less intense activities had higher overestimations when they followed more intense activities. This is problematic for predicting energy expenditure in children, as it is typical for them to alternate between periods of rest or low activity and short bursts of high intensity activity.

Several techniques have been devised to overcome some of the limitations of HR monitoring to predict energy expenditure of physical activity. One method involves developing individual HR-VO_2 calibration curves over a variety of exercise intensities and modes. An example of this method is the FLEX HR. FLEX HR is empirically defined as the mean of the lowest HR during exercise and the highest HR during rest [47]. The FLEX HR is based on the assumption that above a given intensity threshold there is a linear relation between HR and oxygen consumption. Below this threshold, the relation is more variable. Another predictor technique uses the relative HR indices or net HR (work HR - resting HR) [3]. This method attempts to correct for subject-to-subject variation in resting metabolic rate, individual HR, and state of training [5].

FLEX HR is the most studied technique devised for overcoming the limitations of HR monitoring. Ekelund et al. compared TEE estimated by the FLEX HR method (TEE HR) with doubly labeled water (TEE DLW) in eight adolescent male athletes [50]. When comparing methods at the individual level, a –11 to +24% discrepancy range was observed between TEE HR and TEE DLW. In another study, Livingstone et al. examined the accuracy of the FLEX HR method in estimating TEE in 36 free-living children compared to DLW [47]. Individual TEE HR and TEE DLW discrepancies ranged from –16.9 to +18.8%. When examined on a group basis, the TEE HR estimate was +10% of the TEE DLW. The investigators concluded, "The FLEX HR method is a socially acceptable low-interference technique for accurately predicting group estimates of habitual TEE in healthy, free-living children. However, the precision of individual estimates of TEE HR is inevitably constrained by the need to apply contrived and therefore, and most probably, unrepresentative calibration data to complex and spontaneous free-living patterns of energy expenditure [47]".

Though HR monitoring is not recommended to estimate individual energy expenditure of physical activity, it is a valid method for predicting energy expenditure and patterns of physical activity in large groups of free-living people [32]. Heart rate monitors can record data over time, which will allow for assessment of physical activity patterns including frequency, intensity, and duration of activity as well as TEE. Additionally, it is easy to measure, noninvasive, and relatively inexpensive. Heart rate monitoring to predict energy expenditure can be used in a variety of laboratory and field settings.

2.2.5. Doubly Labeled Water

DLW is considered the "gold standard" for measuring energy expenditure in the free living environment [3, 32, 51] This method provides information on total energy expenditure by a free-living individual over a period of 4-20 days [52]. The individual takes an oral dose of water containing known amounts of stable (nonradioactive) isotopes of both hydrogen ($^2H_2$ or deuterium) and oxygen (^{18}O). Within a few hours following consumption, these isotopes mix with the hydrogen and oxygen already present in the body water. As the body uses energy, carbon dioxide (CO_2) and water are produced. Carbon dioxide leaves the body via the breath, while water is lost in breath, urine, sweat, and other evaporations. Since ^{18}O is contained in both CO_2 and water, it is lost from the body more rapidly than $^{2}H_2$, which is contained in water but not in CO_2. The difference between the two isotope elimination rates therefore, is proportional to the total CO_2 produced during the metabolic period [53]. Energy expenditure is then calculated from CO_2 production using standard equations derived from indirect calorimetry [51].

Since 1982 when the DLW method was initially used in humans to measure energy expenditure, this procedure has undergone extensive validation studies. The accuracy and precision of the earlier studies varied depending upon the isotope dose, length of the elimination period, and frequency of sampling (two-point or multipoint). Calculation techniques, standards for comparison and assumptions used in the model were also debated issues. In these earlier studies, the coefficient of variation averaged 5-8%.

In one of the first validation studies, Schoeller et al. compared energy expenditure derived from the doubly labeled water method against measured dietary intake plus change in body composition [54]. Energy expenditure was calculated from energy balance by taking the sum of the dietary intake and the change in body stores (dietary intake balance study). The difference in energy expenditure between the two methods was within 220 kcals for three of the four subjects and 307 kcals in the fourth subject. In this small sample, this amounted to 2% difference in energy expenditure and a coefficient of variation of 6% between the two methods.

In a subsequent study, Schoeller and Webb compared the doubly labeled water method with a respiratory gas exchange procedure [53]. Five subjects lived in a laboratory apartment for five days. During this time, respiratory gas exchange was measured using a facemask that was worn for the 5 days except for 20 minutes at breakfast and lunch and 60 minutes at dinner. All the meals eaten were analyzed for energy content by bomb calorimetry and urine isotope and nitrogen content were calculated. Energy expenditure measured by the DLW and respiratory gas exchange methods differed by 6% and the coefficient of variation between methods was 8%. It was concluded that these differences were not statistically significant [53].

After several years of examining and refining the DLW technique, the coefficient of variation was reduced to 3-5% for the measurement of energy expenditure compared to a criterion measure [55]. In 1990, Seale et al. conducted a study to compare estimates of energy expenditure as determined by the DLW method with measured dietary intake and changes in body stores [56]. Four adult men resided in a room-sized calorimeter on three alternate days during one week of the 13-day study. While in the calorimeter, subjects followed a fixed schedule that closely resembled their normal daily living and received standardized meals. It was found that the percent difference between energy expenditure estimated by adjusted (for weight change) dietary intake and DLW was $-1.04 \pm 0.63\%$. The investigation concluded that there were no significant differences between energy expenditure estimated by the DLW method and dietary intake balance and changes in body stores.

Subsequently, Seale et al. examined the precision and accuracy of the doubly labeled water method to determine energy expenditure using whole room calorimetry as the criterion measure [57]. Nine subjects resided in the calorimeter for five to seven consecutive days. Daily CO_2, water production and energy expenditure were averaged from calorimeter data and compared with $^2H_2{}^{18}O$ results for the 5 or 7-day period. No significant differences were observed between energy expenditure measured by calorimetry (11.0 MJ/day) and doubly labeled water determined using different calculation methods (i.e. 11.17 MJ/day regression 1-multipoint morning urine, 11.07 MJ/day regression 2-multipoint morning and evening urine and 11.16 MJ/day method 3-two-point urine on day 1 and day 8). The percent difference for energy expenditure between calorimetry and each of the DLW methods were 1.55 ± 2.57 (mean $\pm$ SD) for DLW method 1, 0.98 ± 8.19 for DLW method 2 and 1.59 ± 4.50 for method 3 [57].

The DLW method has several advantages over the other techniques described. It is nonrestrictive and ideally suited for use with free-living subjects who can engage in normal activities of daily life during the measurement period. It can be used in a variety of settings and population sub-sets including premature infants, children, obese people, pregnant and lactating women [58]. Energy expenditure can be measured over a relatively long period of time, i.e. up to 3 weeks. The method is safe, painless and unobtrusive [59].

The limiting factor in using the DLW method is the prohibitive cost of the isotope ^{18}O at approximately $400.00-$600.00 per adult subject and $200.00 for a 30 kg child [3]. Additionally, the analysis of the isotopes requires expensive equipment and highly trained technicians, thus further increasing the cost of this procedure [60]. Doubly labeled water cannot be used to differentiate the duration, frequency, intensity of any single episode of physical activity, or patterns of physical activity over time [61]. Accurate dietary records must be obtained during the measurement period in order to calculate energy expenditure [59].

2.2.6. Indirect Calorimetry

As DLW is considered the gold standard for measuring energy expenditure in the free-living environment, indirect calorimetry using respiratory-metabolic measures, is the gold standard in the laboratory setting [44, 62]. Indirect calorimetry is the method by which energy production is measured from oxygen consumption (VO_2) and carbon dioxide (CO_2) production in the body [63]. Air flow and percentage of oxygen and carbon dioxide are precisely measured to determine VO_2 and carbon dioxide consumption (VCO_2) and by calculation, the respiratory exchange ratio (RER) [58]. Assuming that all oxygen is used to oxidize degradable fuels and all the CO_2 evolved is recovered, it is possible to calculate the total amount of energy produced [58]. "It should be clear that "energy production" means conversion of the chemical free-energy of nutrients into the chemical energy of adenosine triphosphate (ATP) plus loss of some energy during the oxidative process. Eventually, however, all energy will be converted into heat [63]."

To validate the accuracy of indirect calorimetry in measuring energy production, the procedure was initially compared to direct calorimetry. Direct calorimetry measures the total heat loss by the body from which energy expenditure can be estimated. When using the direct calorimetry method an individual is placed in a thermically isolated chamber and the heat dissipated by the body (evaporation, radiation, conduction and convection) is collected and measured. "Under conditions of unchanging temperature and energy store repletion, direct and indirect calorimetry simply look at the two sides, removal and production, respectively of the heat balance equation [63]."

Dauncey et al. examined the accuracy of measuring energy expenditure via direct calorimetry (total heat loss) and indirect calorimetry (heat production calculated from VO_2 and VCO_2). Eight subjects lived in a whole-body calorimeter for 28 hours on 3 separate occasions, separated by at least one month. Subjects were fed low, medium, and high caloric diets. Subjects were free to perform a variety of sedentary activities such as reading, watching television, writing and listening to the radio. The mean percent difference between energy expenditure measured via indirect calorimetry and direct calorimetry was only $1.2 \pm 0.14\%$ [64].

Similarly, Seale et al. found no significant differences in energy expenditure determined by direct and indirect calorimetry [56]. Four subjects spent three alternate days over one week in a room-sized calorimeter. Subjects were fed regular meals and followed a fixed schedule that included sleeping, exercising, eating, and participating in free-activity periods. Direct (heat emission) and indirect calorimetry (respiratory gas exchange) data were measured simultaneously and corrected to determine 24-hour energy expenditure. The results indicated that energy expenditure measured in a controlled environment with direct (2798$\pm$25 kcal) and indirect (2816$\pm$31 kcals) calorimetry was equivalent. The mean difference between energy expenditure measured by indirect calorimetry and direct calorimetry was 0.63$\pm$0.44%.

The accuracy and precision of the indirect calorimetry in measuring energy expenditure has made it the method of choice to validate heart rate monitors, pedometers, accelerometers and DLW in the laboratory setting [32]. In general indirect calorimetry has been used to determine the energy cost of specific activities within the laboratory setting.

Although this technique is accurate, there are limitations that restrict its use. Indirect calorimetry is a costly procedure; metabolic systems are priced from $20,000 to $100,000. Trained personnel are required to operate and interpret the results. The respiratory metabolic units, even the portable units, are cumbersome and can alter patterns of physical activity particularly in the free-living environment because of the limitations they place on the individual's movement [32]. In the field, data collection is limited to 8 hours, so 24-hour free-living energy expenditure would have to be extrapolated and this may not be a valid statistical assumption. Short-term data collection does not provide information about daily physical activity patterns under normal living conditions.

2.2.7. Combination Systems

Because of the limitations of the practical field methods for assessing the energy expenditure of physical activity, there have been attempts to combine approaches in an effort to improve validity. In order to improve the precision of heart rate derived estimates of free-living energy expenditure, several investigations have used a combination of heart rate with acclerometry [9]. The principle behind this method is to use a motion sensor as a back-up measure to verify that elevations in heart rate are representative of responses to physical activity. This would help to reduce the variability of heart rate as a single predictive measure, due to intervening factors that increase heart rate and yet do not contribute to energy expenditure [58].

To date several studies have used combined techniques to improve estimates of physical activity energy expenditure. Moon et al. combined heart rate and movement counts (via a physical activity vibration sensor, Act I, Mini-mitter). Heart rate and physical activity counts were monitored in twenty adults for two days while they resided in a room calorimeter and for three days in a free-living environment. During the time spent in the room calorimeter, HR and physical activity counts were calibrated to metabolic rate for each subject. During the three days of free-living, HR and PA were recorded. Using the HR and PA recordings and the individualized calibration data, regression equations were developed to predict both oxygen consumption and carbon dioxide production. It was concluded that the precision of VO_2 and VCO_2 predictions was improved by combining PA monitoring with electronically recorded HR. "Physical activity data were most effective when used to assign HR to separate active and inactive VO_2 and VCO_2 prediction functions than when entered simultaneously with HR in nonlinear equations [65]." The range of prediction errors for VO_2 and VCO_2 were $-3.3\pm3.5\%$ and $-4.6\pm3\%$ respectively.

In another study, Haskell et al. tested the concept of simultaneous recording and analysis of HR and body motion via movement sensors in 19 adult men. Subjects were evaluated while performing seven exercise conditions, including walking and running at various speed and grade combinations, arm cranking, cycling and bench stepping. Heart rate, leg motion, arm motion, and oxygen uptake were recorded. The results demonstrated that the accuracy of estimating oxygen consumption during a wide range of activities improved when individualized HR-VO_2 regressions were used and HR and body movement were analyzed simultaneously rather than separately [66].

In a study previously mentioned, Eston et al. tested the accuracy of various physical activity monitors (HR, pedometry, uniaxial and triaxial accelerometry, and various combinations) to predict oxygen consumption [4]. Thirty Welsh children completed a protocol involving walking and running on a treadmill, playing hopscotch, playing catch, and sitting and coloring. A multiple regression equation that included triaxial accelerometry counts and HR predicted oxygen consumption better than any single or combination measures, with $R^2 = 0.85$.

Conceptually it makes sense that combining techniques would improve the accuracy of measuring energy expenditure using a physical activity monitor. Additionally, the combination of measures helps reduce the limitations inherent in each of the single physical activity monitors. For instance, by combining HR and accelerometry, the measurement of energy expenditure is more accurate and, the increases in HR can be checked against the accelerometer to verify if the increases are related to physical activity. Together these two techniques can provide a clearer picture of patterns of physical activity in the field setting.

2.2.8. Body Media SenseWear® Pro 2 Armband

The SenseWear® Pro 2 Armband uses the combination measurement system to calculate energy expenditure. Preliminary experimental evidence has been equivocal. Fruin conducted a study to examine the reliability and validity of the SenseWear® Pro 2 Armband during rest and exercise [67]. Indirect calorimetry served as the criterion measure. Energy expenditure was measured in thirteen male subjects during two resting and one cycle erogmeter sessions. The cycle ergometer bout consisted of pedaling for 40 minutes at 60 rpm at a fixed load, which represented 60% of the subjects predetermined VO_{2peak}. Data was collected over the forty minutes and reported as three distinct time periods early (1-10 minutes), mid (19-23 minutes) and late (31-40 minutes). Results of a two factor ANOVA (time x device) with repeated measures on time indicated a significant time by device interaction as was reflected by an increase in the SenseWear® Pro 2 Armband estimate of energy expenditure at each time period contrasted by the steady energy expenditure measurement of the respiratory metabolic system. The greatest variation in energy expenditure means occurred during the early time period (8.8% difference, $P \geq 0.07$), although post hoc analysis did not find any significant differences. The correlation between measuring devices was low for each time period early ($r = 0.11$; $P \geq 0.72$), mid ($r = 0.12$; $P \geq 0.70$), and late ($r = 0.03$; $P \geq 0.92$). In addition, the Bland-Altman plots showed wide limits of agreement between the two devices with larger prediction error seen for individuals with the highest and lowest energy expenditures. At rest, no significant differences were found between energy expenditure measurements from the SenseWear® Pro 2 Armband (1.30 ± 0.03kcal/min) and indirect calorimetry (1.29 ± 0.04 kcal/min) for the individual or the combined resting periods.

In a second experiment, Fruin tested 20 adults on a treadmill for 10 minutes each at 3.0 mph, 0% grade; 4 mph, 0% grade; and 4 mph, 5% grade [67]. Energy expenditure measured by the SenseWear® Pro 2 Armband increased with treadmill speed, but not with inclination. The SenseWear® Pro 2 Armband significantly overestimated the energy expenditure of flat walking (27.4% for 3 mph, $p<0.001$; 12.6% for 4 mph, $p<0.02$) and significantly underestimated energy expenditure of walking on a 5% grade (21.9%, $p<0.002$).

King et al. examined the accuracy of the SenseWear® Pro 2 Armband to estimate energy expenditure in adults during treadmill exercise [68]. Nine females and 10 males performed 10-minute interval bouts on the treadmill at six different walking and running speeds. The energy expenditure determined by the SenseWear® Pro 2 Armband increased with increasing treadmill speed. However, the SenseWear® Pro 2 Armband overestimated energy expenditure at all seven treadmill speeds compared to indirect calorimetry [mean (SE) difference for all speeds; 2.1 ± 0.2 $kcal.min^{-1}$, $P < 0.01$]. The SenseWear® Pro 2 Armband was sensitive to changes in energy expenditure over a wide range of walking and running speeds on the treadmill, however, the instrument overestimated energy expenditure compared to indirect calorimetry.

Jakicic et al. evaluated the SenseWear® Pro 2 Armbands ability to accurately estimate energy expenditure during various modes of physical activity [10]. Forty adult subjects completed protocols on the treadmill (30 minutes at 3.0 mph with 10 minutes stages at grades of 0%, 5%), cycle ergometer (two 10-minute stages at 0.5 kg and 1.5 kg break loads), arm ergometer (two 10-minute stages of 50 and 75 rpm at a break load of 1.0 kg), and bench step (two 10-minute stages of 20 steps per minute and 35 steps per minute on an eight inch step). Indirect calorimetry served as the criterion measure. The SenseWear® Pro 2 Armband significantly overestimated energy expenditure during level treadmill walking by 1.3 ± 0.50

kcal·minute^{-1}; (minutes 1-10) and significantly underestimated energy expenditure of walking on a 5 or 10% treadmill grade by 0.3 $\pm$ 0.60 kcal·minute^{-1} (minutes 11-20) and by 2.4 $\pm$ 0.9 kcal·minute^{-1} (minutes 21-30) ($P < 0.016$), respectively. For cycle ergometer exercise, the SenseWear® Pro 2 Armband significantly underestimated energy expenditure by 0.4 $\pm$ 0.80 kcal·minute^{-1} during minutes 1-10 and by 2.9 $\pm$ 1.1 kcal·minute^{-1} during minutes 11-20 ($P < 0.025$). The SenseWear® Pro 2 Armband estimate of the total energy expenditure exercise was also significantly lower for cycle ergometer exercise (32.4 $\pm$ 18.8 total kcal; $P \leq 0.001$) and for walking on the treadmill (14.9 $\pm$ 17.5 total kcal; $P \leq 0.001$) compared to the respiratory metabolic system.

Conflicting results from these preliminary research studies can best be explained by the ongoing revising and updating of the algorithms used by the SenseWear® Pro 2 Armband to calculate energy expenditure. To date there are no published data on the validity of the SenseWear® Pro 2 Armband in studies that have used this device to measure physical activity in adolescents.

Function of the BodyMedia SenseWear® Pro 2 Armband. The combination of sensors makes the BodyMedia SenseWear® Pro 2 Armband unique in its ability to detect and calculate energy expenditure. Among the biometric sensors, the Armband uses a two-axis accelerometer for motion detection. Measuring acceleration of body mass may be useful in estimating energy expenditure [3]. Body movement, muscular activity, and gravity is mapped to forces exerted on the body, which can in turn, can be mapped to energy expended by the muscles of the body to generate these forces. The SenseWear® Pro 2 Armband uses the physical energy as part of the calculation to determine energy expenditure.

The remaining biometric sensors contained in the SenseWear® Pro 2 Armband measure either heat produced by the body or surrounding environment to improve the estimation of energy expenditure. The body dissipates heat to the environment in many forms: heat convection through the skin being in contact with the air, heat conduction through the clothing, evaporation of sweat on the skin, evaporation of exhaled moisture and heat radiation. The SenseWear's heat flux sensor measures the amount of heat being exchanged by the body to the outside environment (heat convection).

The SenseWear® Pro 2 Armband measures skin temperature using a thermistor-based sensor. Thermistors are resistors that change value with temperature [2]. Continuously measured skin temperature, although it is several degrees cooler, is linearly reflective of the body's core temperature. Under laboratory conditions, core body temperature and energy expenditure are closely related [3].

The SenseWear's near-body ambient temperature sensor measures air temperature and the immediate environmental temperature around the armband. The rate of change in near-ambient temperature can be used to delineate changes in core temperature due to the changes in environmental temperature.

Also included in the SenseWear® Pro 2 Armband system are two stainless steel electrodes which measure galvanic skin response (GSR). Galvanic skin response measures the electrical conductivity between two points on the skin. A low level electric voltage is applied to the skin and the skin's conduction of the current is measured. GSR reflects evaporative heat loss and can be an indicator for the onset, peak, and recovery of maximal sweat rates [2].

Along with these sensors, the SenseWear® Pro 2 Armband system has the option to monitor heart rate. Instantaneous heart rate is recorded providing information on frequency, intensity, and duration of physical activity patterns. The physiologic information gathered by all of the sensors along with knowledge of simple body measurements such as weight, height, age, gender, etc, are processed using SenseWear's algorithms to provide estimations of energy expenditure.

SenseWear® Pro 2 Armband utilizes contextual information in the calculation of energy expenditure which greatly enhances its reliability and accuracy [2]. The SenseWear® Pro 2 Armband has the ability to accurately detect contexts in free-living situations including exercising, motoring, watching television, getting into and out of bed [11]. As a result, the SenseWear® Pro 2 Armband has the capability to filter out erroneous sources of movement such as driving a car, which might falsely elevate estimates of energy expenditure. This fact has significant ramifications for the SenseWear® Pro 2 Armband's ability to accurately detect energy expenditure in free-living situations and sets the Armband apart from other energy detection devices.

2.3. CONCLUSION

A physical activity monitor, like the SenseWear® Pro 2 Armband that accurately estimates physical activity duration, intensity and energy expenditure in the free living environment could be used to help answer long standing questions about physical activity patterns, energy imbalance, compliance with physical activity guidelines and the dose-response relation between physical activity and health. Therefore, the purpose of this study was to examine the validity of the SenseWear® Pro 2 Armband as a measuring tool for assessing energy expenditure during various modes of physical activity in children.

3. CHAPTER 3

METHODOLOGY

3.1. SUBJECTS

The study sample consisted of adolescents (12 boys and 12 girls) between the ages of 12-17years. Subjects had normal body weight as defined by <85th (CDC 1996) but greater than the 5th (WHO, 1996) percentile for body mass index adjusted for age, height and gender (Appendix A). A summary of descriptive characteristics for all subjects is provided in Table 1. All subjects were volunteers and were recruited from the greater Pittsburgh region. The Pre-Participation Medical Screening & Physical Activity History (Appendix B) was used to determine if the subjects were in good health and did not have contraindications to exercise. All subjects and their parents provided written informed consent and assent prior to participating in this study. At the completion of the study, each research subject was paid $30.00. The Institutional Review Board at the University of Pittsburgh approved all procedures as of January 6, 2004.

Table 1: Subject's Descriptive Data

Variable	Females	Males	Total Sample
Age (yr)	13.9 ± 1.6	13.8 ± 2.0	13.8 ± 1.8
Height (cm)	164.8 ± 6.2	161.0 ± 14.3	162.9 ± 11.0
Weight (kg)	57.7 ± 6.5	50.8 ± 12.7	54.2 ± 10.5
BMI (kg/m^2)*	21.2 ± 1.4	19.2 ± 2.4	20.2 ± 2.1
Body Fat (%)*	27.6 ± 5.3	12.1 ± 4.0	19.8 ± 9.2
Triceps Skinfold (mm)*	13.0 + 2.6	9.4 + 2.6	11.2 + 3.1

Values are mean ± Standard deviation (SD)

*Indicates difference between genders ($p < 0.05$)

Sample size calculations were computed a priori using Jan deLeeuw's Web-Based Statistics [69]. The available data from previous SenseWear® Pro 2 Armband research was not used in the power analysis calculations as they were derived from limited samples and the standard deviations were excessively large. As such, a study conducted by Nichols et al. validating a triaxial accelerometer against indirect calorimetry, where the dependent variable was energy expenditure was used in the power calculation. The calculation indicated that a minimum sample size of 12 subjects was required for a statistical power of P=0.80 and $p < 0.05$ within each gender classification.

3.2. EXPERIMENTAL DESIGN

This investigation used a cross sectional, within subject, counterbalanced design having two experimental trials. The independent variables for the investigation were gender, exercise mode (treadmill and cycle ergometer) and type of device. The dependent variables were 1) energy expenditure in $kcal \cdot min^{-1}$ and 2) total energy expenditure in kcal.

The investigation consisted of one orientation session and one experimental testing session consisting of two exercise trials: 1) treadmill and 2) cycle ergometer (see Figure 3). The investigation was completed in one day and there was a 40-minute rest period (listening to music, playing on the computer, talking to other subjects) between the two exercise trials. A counterbalanced design was used to assign the order of the exercise mode across experimental trials.

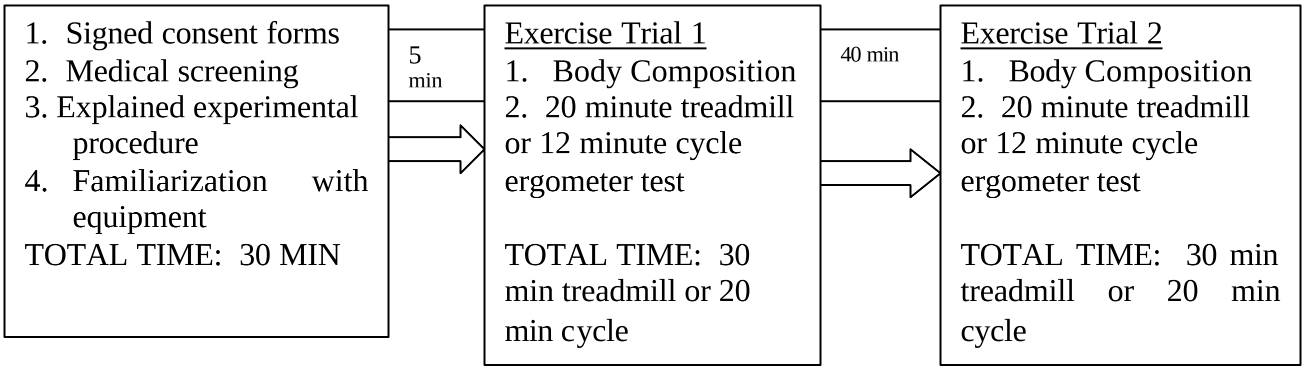


Figure 3 Schematic Diagram of the Experimental Sequence

3.3. ENERGY EXPENDITURE MEASUREMENT

All testing was done in the Center for Exercise and Health Fitness Research in Trees Hall at the University of Pittsburgh.

<u>Cycle Ergometer</u>: A Monark Cycle Ergometer Model # 818 was used to conduct the cycle experimental trial.

<u>Treadmill:</u> A Trackmaster TMX425 was used to conduct the treadmill experimental trial.

<u>Indirect Calorimetry:</u> Energy expenditure measured by indirect calorimetry served as the dependent variable. Data was collected at one-minute intervals using an open circuit respiratory-metabolic system (Parvomedics TrueMax 2400 Metabolic Measurement System). The electronic analyzers were calibrated immediately prior to testing and at the completion of each exercise bout using standard reference gases. Depending on comfort and ability to make a tight seal around the mouthpiece with the lips, either a child or an adult respiratory valve and mouthpiece was used.

SenseWear® Pro 2 Armband: A SenseWear® Pro 2 Armband (Body Media, Pittsburgh, PA) was used to estimate energy expenditure. This system consists of an array of physiological sensors (heat flux sensor, skin temperature sensor, near-body ambient temperature sensor and galvanic skin response sensor) and a two-axis accelerometer that collects and records data. The measured exercise data were converted to energy expenditure using algorithms in BodyMedia's InnerView™ Research Software Version 4.0.610. Participants wore the SenseWear® Pro 2 Armband positioned at the midpoint on the triceps of the upper right arm. The midpoint was determined by measuring the length of the upper arm between the acromion and oleocranon processes.

Due to the presence of heat flux, GSR, and skin temperature sensors in the SenseWear® Pro 2 Armband, the device was positioned so that it was in constant contact with the skin and placed in a position free from potential interference from clothing and accessories [2]. The triceps position meets these requirements and provided a convenient, unobtrusive, and stable platform on which to position the SenseWear® Pro 2 Armband.

3.4. EXPERIMENTAL PROCEDURES

3.4.1. Recruitment

All subjects were volunteers and were recruited from the greater Pittsburgh region. As subjects were recruited, an appointment was scheduled for the orientation and experimental testing sessions at the Center for Exercise and Health Fitness Research in Trees Hall at the University of Pittsburgh. Recruits were instructed to refrain from eating at least 2 hours and from exercising at least 12 hours prior to arriving at the research laboratory.

3.4.2. Orientation Session

The orientation session was conducted at the Center for Exercise and Health Fitness Research. An explanation of the purpose and overall procedure for the research study was given to the subjects and a parent/guardian. After the study overview, the subject and parent/guardian read the informed consent document. If neither the subject nor the parent/guardian had questions or concerns, the informed consent was signed. Both the subject and the parent/guardian completed the Pre-Participation Medical Screening & Physical Activity History. Only those subjects meeting the inclusion criteria were eligible to participate in the research study. Subjects underwent a familiarization procedure that involved a 3 minute walk on a level treadmill at 2 mph and 3 minutes pedaling on the cycle ergometer at 0 resistance. During these familiarization trials, the subject was fitted with a Polar heart rate monitor, mouthpiece and nose clip and connected to the open circuit respiratory-metabolic system and a SenseWear® Pro 2 Armband was placed on the upper right arm over the triceps.

3.4.3. Experimental Testing Session

The experimental exercise trials was performed in a counterbalanced order and separated by a 40-minute time period. The pretest preparation began with obtaining anthropometric measurements. Each subject was weighed to the nearest 0.5-kilogram and body fat determinations were made to the nearest 0.1% using bioelectrical impedance analysis (BIA; Valjalla Scientific Industries, San Diego, CA). Subjects were weighed and measured in light clothes consisting of a short sleeve tee shirt, shorts, without shoes. Height was measured to the nearest 0.5 centimeters on a Detecto Physicians Scale. From these body measurements, Body mass index was calculated based on current weight and height measurements using the CDC's BMI-for-Age-Growth Charts (Appendix A). Triceps skinfold was measured using Lange

Calipers. The triceps skinfold site measured was on the posterior aspect of the right arm, over the triceps muscle, midway between the lateral projection of the acromion process of the scapula and the inferior margin of the olecranon process of the ulna (Lee, 2003). Three measurements were taken and averaged, then compared to the Triceps Skinfold Norms from NHANES II (Appendix C).

A SenseWear® Pro 2 Armband was placed at the midpoint between the acromion and olecranon processes on the subject's right upper arm over the triceps muscle 15 minutes prior to the start of the exercise testing trial. Once the armband was secure on the arm, a time stamp was made to indicate the start of the 15 minutes adjustment period. Next, the subject was fitted for and wore a Polar Advantage heart rate monitor. Heart rate was recorded the last 15 seconds of each minute of the 4-minute stages.

As the subject was fitted with the exercise testing equipment, the researcher explained the use of this equipment to the subject; i.e. respiratory-metabolic system, SenseWear® Pro 2 Armband, polar heart rate monitor, and either the treadmill or the cycle ergometer as determined by the counterbalance sequence. The respiratory-metabolic system was be calibrated. The nose clip was positioned over the nostrils of the subject so that no air exchange would occur via the nose. The mouthpiece was placed in the subject's mouth and the lips formed a tight seal around it so that air will not escape. The subject was instructed to breathe through the mouthpiece attached to the respiratory- metabolic system for one minute before data were recorded. Oxygen consumption was measured for 5 minutes prior to the exercise test to allow stabilization of respiratory-metabolic measurements. These measurements were analyzed independent of total exercise time as a separate time period. Energy expenditure was assessed simultaneously using indirect calorimetry and the SenseWear® Pro 2 Armband.

The treadmill protocol was adapted from the Modified Balke Treadmill Protocol for Children as described by the American College of Sports Medicine. The rationale for choosing the speed and grade combinations in the present test protocol was to validate the SenseWear® Pro 2 Armband on modes and intensities of exercise typical of adolescent play. The four-minute exercise stages were intended to allow sufficient time to establish a steady state physiological response. The subjects were positioned on the treadmill. The respiratory valve, mouthpiece and nose clip were placed in position. The test will proceed as follows:

Table 2: Treadmill Test Protocol

Phase	Time	Protocol
Warmup	2 minutes	Walk 2.0 miles per hour (mph) 0% grade
Testing	4 minutes	Walk 3.0 mph 0% grade
	4 minutes	Walk 4.0 mph 0% grade
	4 minutes	Walk/Jog 4.0 mph 5% grade
	4 minutes	Walk/Jog4.5 mph 5% grade
Cool Down	2 minutes	Walk decreasing speed to 0 mph 0% grade
TOTAL TIME	20 minutes	Total Distance ~1.2 miles

A Polar Advantage heart rate monitor was worn to record heart rate during the last 15 seconds of each minute of the warm-up, testing and cool down stages. Respiratory metabolic measures (i.e. VO_2, RER, $V_{E(STPD)}$) were determined every one minute throughout the exercise trial. Heat flux and body movement were measured by the SenseWear® Pro 2 Armband and stored directly in the unit. For each subject, the stored data was downloaded into the

InnerView™ Research Software Version 4.0.610. Data was collected at one-minute intervals and converted to energy expenditure using algorithms developed by BodyMedia.

The cycle protocol was adapted from the McMaster Cycle Test for Children as described by the American College of Sports Medicine. The rationale for choosing the speed combinations in the present test protocol was to validate the SenseWear® Pro 2 Armband on a range of intensities typical of adolescent play. The four-minute exercise stages were intended to allow sufficient time to establish a steady state physiological response.

The subject was positioned on the cycle in an upright position with a 5-degree bend in the knee during leg extension and with hands gripping the handlebars. The pedaling pace (revolutions per minute) was regulated using a metronome. The respiratory valve, mouthpiece and nose clip were placed in position. The cycle ergometer protocol was as follows:

Table 3: Cycle Ergometer Test Protocol

Phase	Time	Protocol
Warmup	2 minutes	Pedaling at 50 revolutions per minute (rpm), 0 Watts
Testing	4 minutes	Pedaling 50 rpm, Power output 25 Watts
	4 minutes	Pedaling 50 rpm, Power output 50 Watts
Cool down	2 minutes	Pedaling 0 Watts
TOTAL TIME	12 minutes	

A Polar Advantage heart rate monitor was worn to record heart rate during the last 15 seconds of each minute of the warm-up, testing and cool down stages. Respiratory metabolic measures (i.e. VO_2, RER, $V_{E(STPD)}$) were determined every one minute throughout the exercise trial. Heat flux and body movement were measured by the SenseWear® Pro 2 Armband and stored directly in the unit. For each subject, the stored data was downloaded into the InnerView™ Research Software Version 4.0.610. Data was collected at one-minute intervals and converted to energy expenditure using algorithms developed by BodyMedia using the InnerView™ Research Software Version 4.0.610.

3.5. STATISTICAL ANALYSIS

All analyses were performed using SPSS for Windows (version 12.1) and statistical significance was be accepted at $p<0.05$. Descriptive characteristics of subjects and experimental test responses are presented as means ± standard deviations. Data were analyzed separately for the treadmill and cycle erogometer exercise trials. A two-factor (device X time) analysis of variance (ANOVA) with repeated measures across time was used to test for significant differences both energy expenditure in calories per minute ($kcal \cdot min^{-1}$) and total energy expenditure (kcal). For the respiratory metabolic device, energy expenditure in $kcal \cdot minute^{-1}$ was calculated from oxygen consumption with caloric equivalents corrected for the respiratory exchange ratio (RER) using data from the fourth minute of each exercise stage. For the SenseWear® Pro 2 Armband device, energy expenditure was calculated in $kcal \cdot min^{-1}$ according to algorithms developed by BodyMedia using data from the fourth minute of each exercise stage. Total energy expenditure was calculated as a sum across each exercise testing trial. Total energy expenditure and resting energy expenditure were analyzed with dependent t-tests to compare responses between the respiratory metabolic system and the SenseWear Pro® 2 Armband. Significant main and interaction effects were decomposed with a Simple Effects *post hoc* analysis. Intraclass correlation coefficients were calculated using the kcal per minute ($kcal \cdot minute^{-1}$) data from each subject for each exercise stage. The correlation was used to describe the strength of the relation between these two measuring devices for estimating energy expenditure. In addition, data were analyzed using the procedure described by Altman and Bland [70] to assess the differences between energy expenditure measured using the respiratory metabolic system and estimated using the SenseWear Pro® 2 Armband. A one-way ANOVA was calculated to determine if there was an effect of testing order (Appendix C). No order effect was detected.

4. CHAPTER 4

RESULTS

The purpose of this investigation was to examine the validity of the SenseWear® Pro 2 Armband to assess energy expenditure during walking, jogging, and cycling in adolescents aged 12-17 years.

4.1. SUBJECTS

Twenty-four healthy normal weight adolescents participated in this validation study. A summary of descriptive characteristics for all subjects is provided in Table 1 (Chapter 3, Methods). There were no significant differences (p>0.5) between females and males in age, height and body weight. Body mass index, percent body fat and triceps skinfold were greater (p< 0.05) in the female than male group (see Table 1, Chapter 3, Methods). Means ± standard deviations (SD) for heart rate and MET responses during the cycle ergometer and treadmill trials for the female and male subjects are listed in Table 4.

Table 4: Means (±SD) for Heart Rate and MET Responses during Cycle Ergometer and Treadmill Exercise

Exercise Mode	Exercise Stage	Heart Rate	METs
Cycle Ergometer	50 rpm 25 Watts	105.3 ± 13.0	3
	50 rpm 50 Watts	121.8 ± 14.6	4
Treadmill	3.0 mph, 0% grade	111.2 ± 10.8	4
	4.0 mph, 0% grade	129.8 ± 13.2	5
	4.0 mph, 5% grade	150.3 ± 15.4	7
	4.5 mph, 5% grade	170.5 ± 15.5	9

4.2. CALCULATION OF ENERGY EXPENDITURE

The dependent variables for the investigation were energy expenditure in $kcal \cdot min^{-1}$ and total kcals determined by a respiratory metabolic system and the SenseWear® Pro 2 Armband. Using respiratory metabolism, energy expenditure was calculated from oxygen consumption with caloric equivalents corrected for the respiratory exchange ratio (RER). Energy expenditure was calculated in $kcal \cdot minute^{-1}$ using VO_2 measured during the fourth minute of each exercise stage. Energy expenditure from SenseWear® Pro 2 Armband was calculated in $kcal \cdot minute^{-1}$ using data from the fourth minute of each exercise stage. The fourth minute was chosen, as it was assumed that if present, a physiological steady state would be evident at this time period. Total energy expenditure in kcals was summed across each exercise testing trial (the warmup, exercise stages, and the cool down). The SenseWear® Pro 2 Armband calculations were performed using algorithms developed by BodyMedia. Energy expenditure data in $kcal \cdot minute^{-1}$ and total kcals were analyzed separately for each exercise protocol. Statistical significance was accepted as an alpha of < 0.5.

4.3. MEASURES OF ENERGY EXPENDITURE COMPARED SEPARTELY IN FEMALES AND MALES

It was hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SenseWear® Pro 2 Armband and the respiratory metabolic system when compared separately for the female and male samples.

4.3.1. Cycle Ergometer: Female Subjects

Means $\pm$ standard deviations (SD) for energy expenditure in $kcal \cdot minute^{-1}$ during cycle ergometer exercise are plotted in Figure 4 for female subjects. A two factor (device x time) repeated measures ANOVA was calculated to assess differences in energy expenditure (kcal·minute^{-1}) between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages (Appendix D). A summary of the two factor ANOVA for these data is displayed in figure 4. The ANOVA indicated significant time ($F_{1,11}$ = 34.226, P < 0.001) and device ($F_{1,11}$ = 105.015, P < 0.001) effects. Both measurement device and time were considered as within-subjects variables in the repeated measures ANOVA. In addition, the time by device interaction effect ($F_{1,11}$ = 24.024, P < 0.001) was significant. *Post hoc* analysis of the interaction indicated that energy expenditure (kcal·minute^{-1}) was significantly lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 1.59 ± 0.60 kcal·minute^{-1} (P < 0.001) for stage 1 and 2.60 ± 0.94 kcal·minute^{-1} (P < 0.001) for stage 2 respectively (Appendix E).

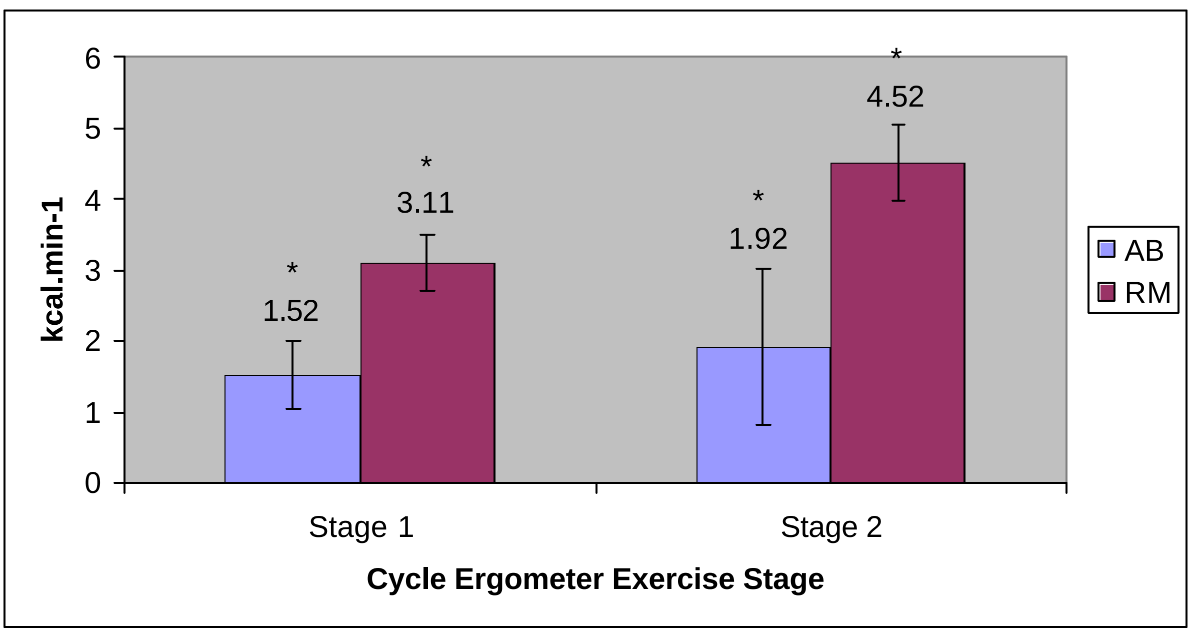


Figure 4: Energy Expenditure (kcal·min^{-1}) During Cycle Ergometer Exercise in Adolescent Female Subjects
*****(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

A Bland-Altman plot is an analysis technique that determines whether two methods agree sufficiently for them to be used interchangeably. The Bland-Altman plot is provided here to describe points of agreement/disagreement between devices using individual data points by subject. For female subjects, the plots indicate low agreement between the two devices. A representative Bland-Altman plot is presented in figure 5 for stage 1 of the cycle ergometer trial. The Bland-Altman plot of energy expenditure data for stage 2 is presented in Appendix F.

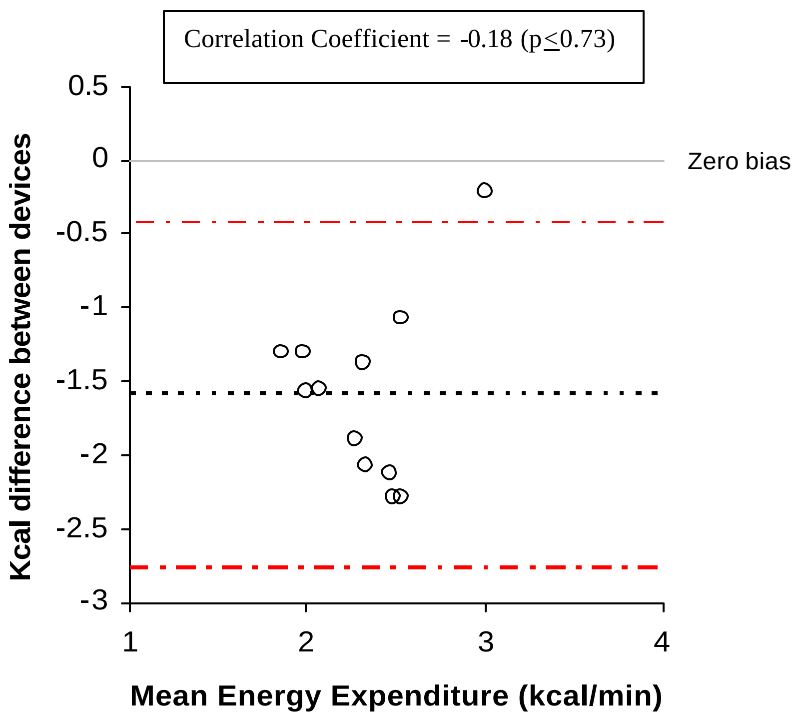


Figure 5: Bland-Altman Plot Stage 1 Cycle Ergometer for Female Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure from each cycle ergometer stage for the respiratory metabolic system and SenseWear® Pro 2 Armband (Appendix G). The intraclass correlations were 0.008 [95% confidence interval (CI): -0.044-0.154] for Stage 1 and 0.074 (CI: -0.048-0.356) for Stage 2. These intraclass correlation coefficients were low and consistent with the Bland-Altman plots that indicated poor agreement between devices measuring energy expenditure in adolescent female subjects on the cycle ergometer protocol.

4.3.2. Cycle Ergometer: Male Subjects

Means $\pm$ standard deviations (SD) for energy expenditure in $kcal \cdot minute^{-1}$ during cycle ergometer exercise are plotted in Figure 6 for the male subjects. One of the twelve male subjects was removed from the statistical analysis of the cycle ergometer data due to equipment malfunction. A two factor (device x time) repeated measures ANOVA was calculated to assess differences in $kcal \cdot minute^{-1}$ between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages for the cycle ergometer protocol (Appendix H). A summary of the two factor ANOVA for these data is displayed in figure 6. The ANOVA indicated significant time ($F_{1,10} = 12.780$, $P < 0.005$) and device ($F_{1,10} = 90.871$, $P < 0.001$) main effects. In addition, the time by device interaction effect ($F_{1,10} = 9.559$, $P < 0.011$) was significant. *Post hoc* analysis of the interaction effect indicated that energy expenditure ($kcal \cdot minute^{-1}$) was significantly lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 1.46 $\pm$ 0.62 $kcal \cdot minute^{-1}$ ($P < 0.001$) for stage 1 and 2.64 $\pm$ 0.99 $kcal \cdot minute^{-1}$ ($P < 0.001$) for stage 2 respectively (Appendix I).

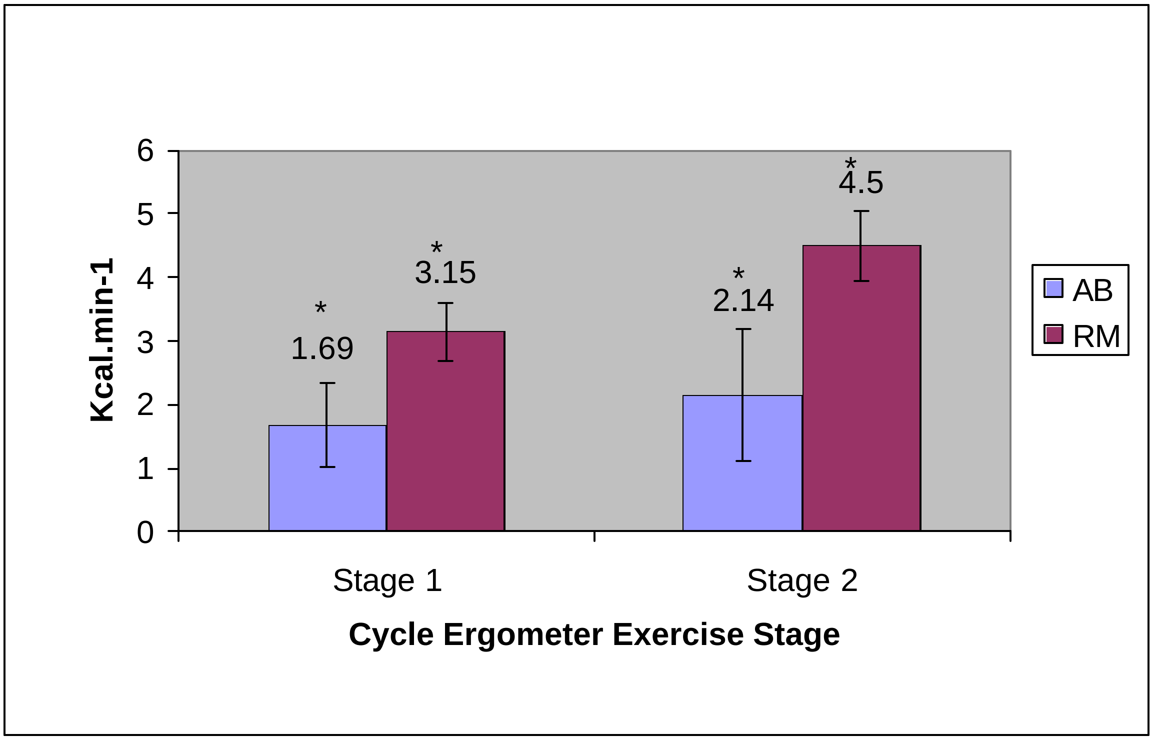


Figure 6: Energy Expenditure (kcal · minute^{-1}) During Cycle Ergometer Exercise in Adolescent Male Subjects

*(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots were calculated to assess the agreement between measuring devices for male subjects on the cycle ergometer protocol. The plots indicated low agreement between the two devices for both exercise stages. A representative Bland-Altman plot is presented in figure 7 for stage 1 of the cycle ergometer trial. The Bland-Altman plot for stage 2 can be found in Appendix J. In general, the trend indicated that the higher the energy expenditure, the lower the agreement between measuring devices as observed in the Bland-Altman plots.

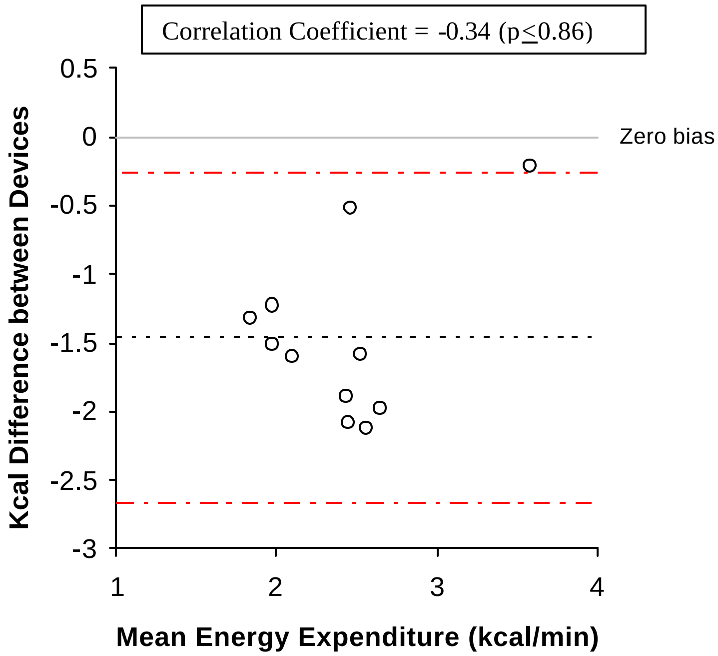


Figure 7: Bland-Altman Plot Stage 1 Cycle Ergometer for Male Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure (kcal · minute^{-1}) from each cycle ergometer stage for the respiratory metabolic system and SenseWear® Pro 2 Armband (Appendix K). For the male subjects, the intraclass correlations were 0.094 [95% confidence interval (CI): -0.063-0.428] for Stage 1 and 0.059 (CI: -0.056-0.335) for Stage 2. These low correlations are consistent with the poor agreement observed in the Bland-Altman plots of the cycle ergometer energy expenditure data for male subjects.

4.3.3. Treadmill Exercise: Female Subjects

Means ± standard deviations (SD) for energy expenditure ($kcal \cdot minute^{-1}$) during treadmill exercise are plotted in Figure 8 for the female subjects. A two factor (device x time) repeated measures ANOVA was calculated to assess differences in energy expenditure ($kcal \cdot minute^{-1}$) between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages for the treadmill protocol (Appendix L). A summary of the two factor ANOVA for these data is displayed in figure 8. The ANOVA indicated significant time ($F_{1,11}$ = 241.258, P < 0.001) and device ($F_{1,11}$ = 194.195, P < 0.001) main effects. In addition, the time by device interaction effect ($F_{1,11}$ = 59.833, P < 0.001) was significant. *Post hoc* analysis of the interaction effect indicated that energy expenditure ($kcal \cdot minute^{-1}$) was significantly lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 0.66 ± 0.55 $kcal \cdot minute^{-1}$ (P < 0.002) for stage 1, 1.34 ± 0.70 $kcal \cdot minute^{-1}$ (P < 0.001) for stage 2, 2.90 ± 0.81 $kcal \cdot minute^{-1}$ (P < 0.001) for stage 3, and 3.71 + 0.94 $kcal \cdot minute^{-1}$ (P < 0.001) for stage 4 respectively (Appendix M).

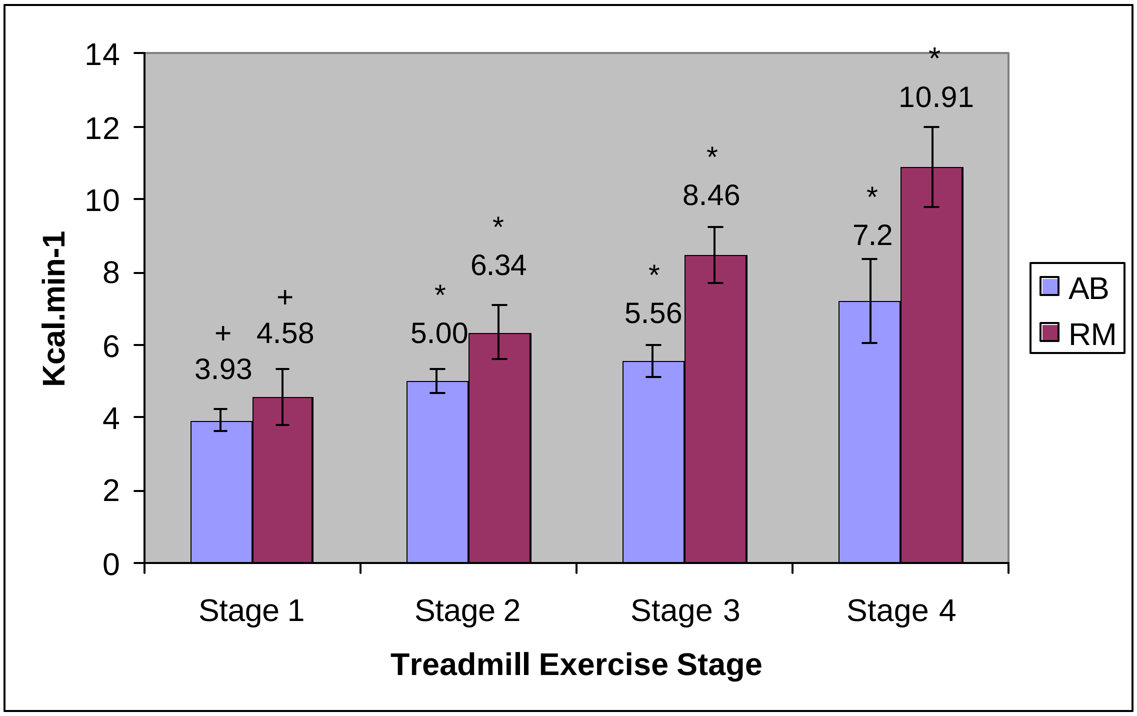


Figure 8: Energy Expenditure (kcal·minute^{-1}) during Treadmill Exercise in Female Subjects + (P < 0.002); * (P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots indicated low agreement between the two devices for each of the four stages of the treadmill protocol (Appendix N). A representative Bland-Altman plot is presented in figure 9 for stage 1 of the treadmill trial. In general, during stages 1 through 3 the trend indicated the higher the energy expenditure, the lower the agreement between measuring devices. However by stage 4, lower agreement between devices was observed in the Bland-Altman plots at both the lowest and highest energy expenditures.

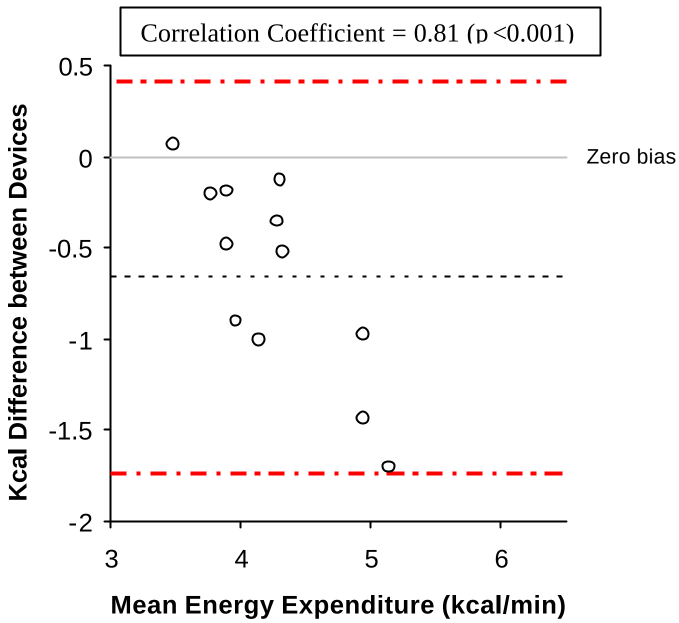


Figure 9: Bland-Altman Plot Treadmill Stage 1 for Female Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure from each treadmill stage for the respiratory metabolic system and SenseWear® Pro 2 Armband (Appendix O). The intraclass correlations were 0.349 [95% confidence interval (CI): -0.125-0.742] for Stage 1, 0.065 (CI: -0.075-0.358) for Stage 2, 0.014 (CI: -0.025-0.130) for stage 3, and 0.101 (CI: -0.028-0.427) for stage 4. These correlations were low, consistent with the poor agreement observed in the Bland-Altman plots of the treadmill energy expenditure data for female subjects.

4.3.4. Treadmill Exercise: Male Subjects

Means ± standard deviations (SD) for energy expenditure (kcal·minute^{-1}) during treadmill exercise are plotted in Figure 10 for the male subjects. A two factor (device x time) repeated measures ANOVA was calculated to assess differences in energy expenditure (kcal·minute^{-1}) between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages for the treadmill protocol (Appendix P). A summary of the two factor ANOVA for these data is displayed in figure 10. The ANOVA indicated significant time ($F_{1,11} = 133.038$, $P < 0.001$) and device ($F_{1,11} = 10.390$, $P < 0.008$) main effects. In addition, the time by device interaction effect ($F_{1,11} = 20.519$, $P < 0.001$) was significant. *Post hoc* analysis of the interaction effect indicated that energy expenditure (kcal·minute^{1}) did not differ between devices at treadmill stages 1 and 2. Energy expenditure was significantly lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 1.36 ± 1.47 kcal·minute^{1} ($P < 0.008$) at stage 3, and 2.22 ± 1.73 kcal·minute^{1} ($P < 0.01$) at stage 4 respectively (Appendix Q).

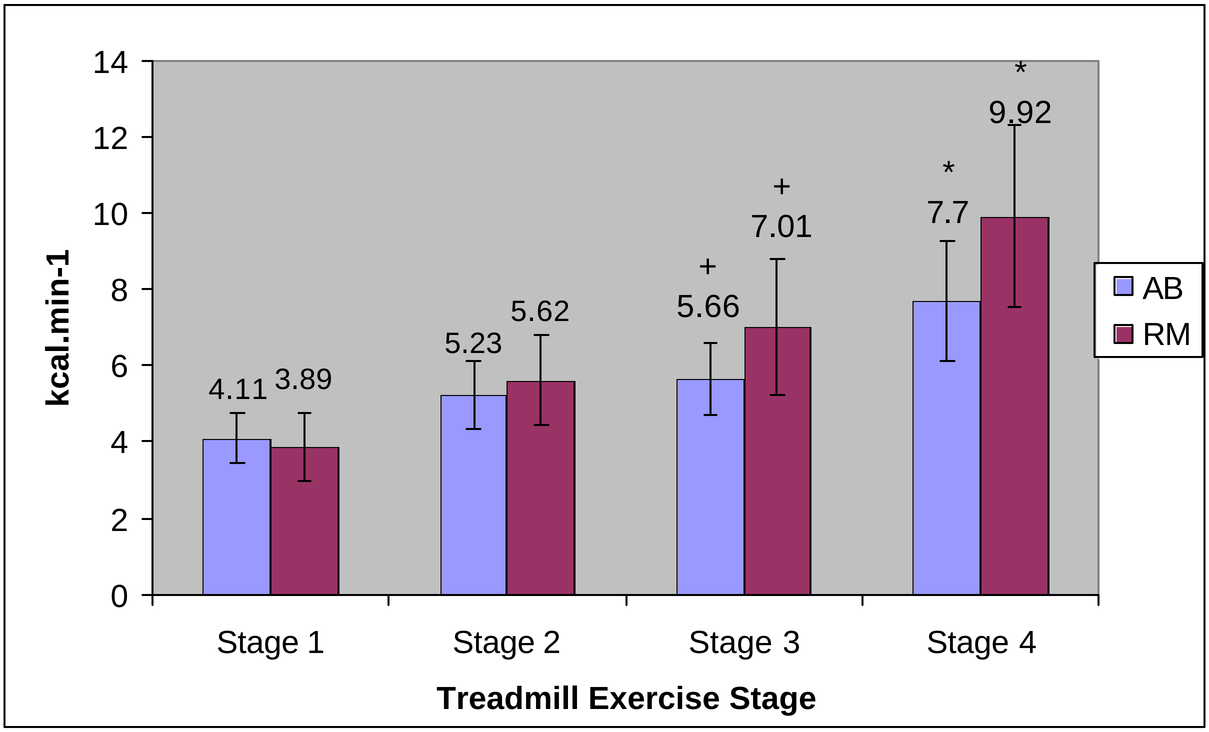


Figure 10: Energy Expenditure (kcal·minute^{-1}) During Treadmill Exercise in Male Subjects
+ (P < 0.008); *(P, 0.01) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

The Bland-Altman plots indicate good agreement between the two devices for two of the four exercise stages (stages 1 and 2) of the treadmill protocol (Appendix R). A representative Bland-Altman plot is presented in figure 11 for stage 1 of the treadmill trial. This Bland-Altman plot shows good agreement between the two measuring devices as is evidenced by the close proximity of the mean difference line (middle dashed line) to the zero bias line. However, the Bland-Altman plots for stages 3 and 4 of the treadmill protocol indicate low agreement between the two devices (Appendix R). The plots for stages 3 and 4 show lower agreement for individuals with the highest energy expenditure.

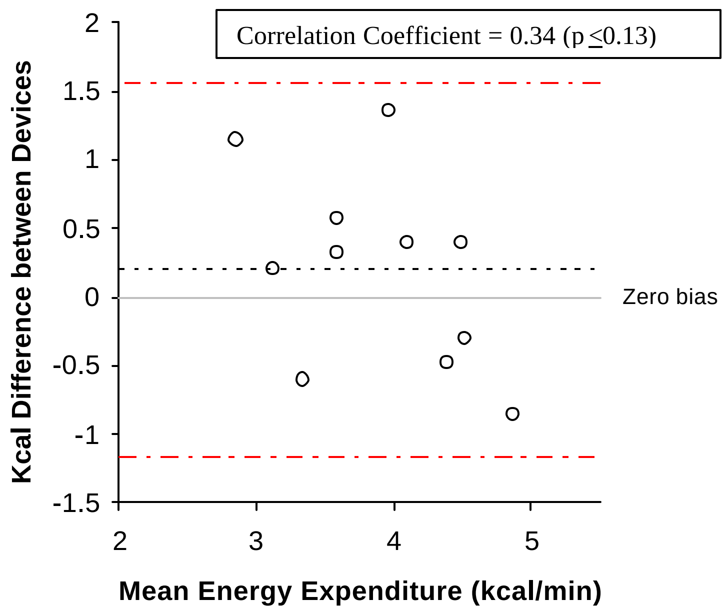


Figure 11: Bland-Altman Plot Treadmill Stage 1 for Male Subjects

Kcal difference between devices= Energy expenditure in $kcal \cdot min^{-1}$ from Respiratory metabolic system minus energy expenditure in $kcal \cdot min^{-1}$ from SenseWear Pro 2 Armband; **Mean Energy Expenditure ($kcal \cdot min^{-1}$)**= Energy expenditure in $kcal \cdot min^{-1}$ from Respiratory metabolic system minus energy expenditure in $kcal \cdot min^{-1}$ from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure from each treadmill stage for the respiratory metabolic system and SenseWear® Pro 2 Armband. For the male subjects, the intraclass correlations were 0.630 [95% confidence interval (CI): 0.145-0.875] for Stage 1, 0.731 (CI: 0.300-0.914) for Stage 2, 0.325 (CI: -0.129-0.719) for Stage 3, and 0.404 (CI: -0.121-0.784) for Stage 4 (Appendix S). The correlations for stages 1 and 2 are moderate which is consistent with the good agreement observed in the Bland-Altman plots between energy expenditure data from level treadmill walking for male subjects. In stages 3 and 4 however, the correlations decrease and are reflective of the poor agreement between measures of energy expenditure between devices for graded treadmill walking in adolescent males.

4.4. Measures of Energy Expenditure in a Combined Group of Female and Male Subjects

It was hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SenseWear® Pro 2 Armband and the respiratory metabolic procedures when calculations were based on a combined group of 12-17 year old female and male adolescents.

4.4.1. Cycle Ergometer

Means ± standard deviations (SD) for energy expenditure ($kcal \cdot minute^{-1}$) during cycle ergometer exercise are plotted in Figure 12 for the combined group (n=23). A two factor (device x time) repeated measures ANOVA was calculated to assess differences in energy expenditure between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages for the cycle ergometer protocol (Appendix T). A summary of the two factor ANOVA for these data is displayed in figure 12. The ANOVA indicated significant time ($F_{1,22} = 40.545$, $P < 0.001$) and device ($F_{1,22} = 201.535$, $P < 0.001$) main effects. In addition, the time by device interaction effect ($F_{1,22} = 30.820$, $P < 0.001$) was significant. *Post hoc* analysis of the interaction effect indicated that energy expenditure ($kcal \cdot minute^{-1}$) was lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 1.53 ± 0.60 $kcal \cdot minute^{-1}$ ($P < 0.001$) for stage 1 and 2.48 ± 0.95 $kcal \cdot minute^{-1}$ ($P < 0.001$) for stage 2 respectively (Appendix U).

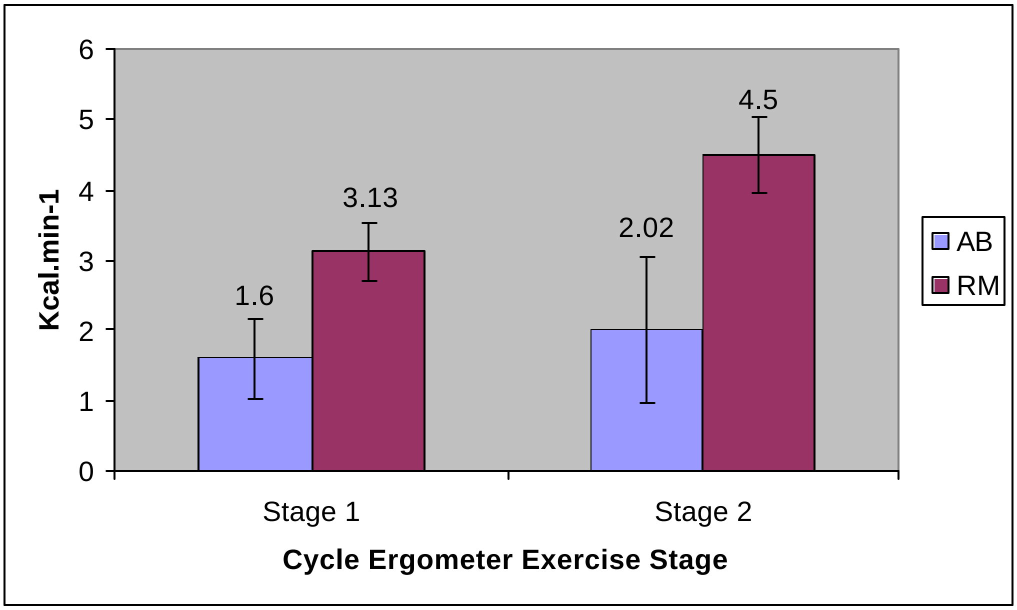


Figure 12: Energy Expenditure ($kcal \cdot minute^{-1}$) During Cycle Ergometer Exercise in the Combined Male & Female Group

*($P < 0.001$) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

The Bland-Altman plots indicated low agreement between the two devices for both cycle ergometer exercise stages in the combined group of female and male subjects (Appendix V). A representative Bland-Altman plot is presented in figure 13 for stage 1 of the cycle ergometer trial. This plot shows that in stage 1 the lowest agreement between devices was observed for individuals with a mean energy expenditure of 2.5 $kcal \cdot minute^{-1}$. In stage 2, the plot indicates there was poor agreement observed at the lower energy expenditures (Appendix V).

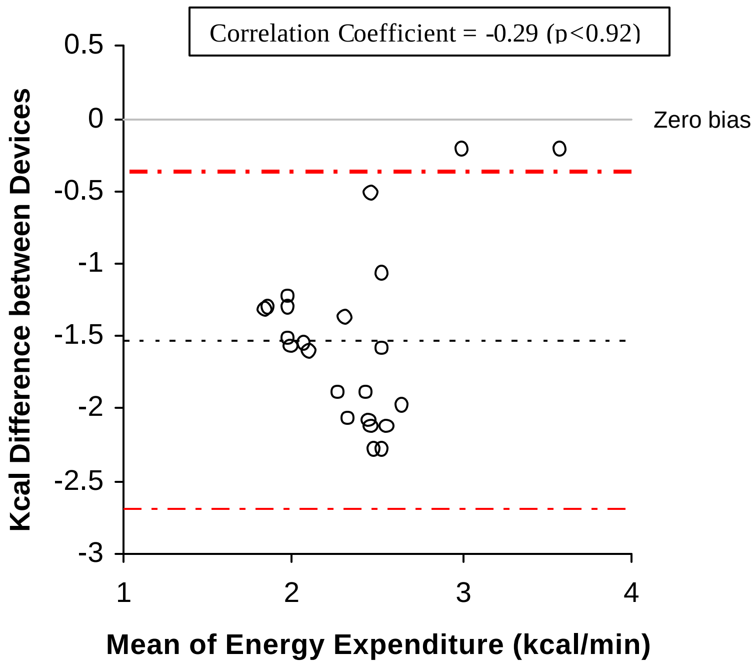


Figure 13: Bland-Altman Plot Cycle Ergometer Stage 1 for the Combined Group of Female and Male Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure from each cycle ergometer stage for the respiratory metabolic system and SenseWear® Pro 2 Armband. The intraclass correlations were 0.047 [95% confidence interval (CI): -0.045-0.219] for Stage 1 and 0.064 (CI: -0.048-0.273) for Stage 2 (Appendix W). These correlations were low, consistent with the poor agreement observed in the Bland-Altman plots for measures of energy expenditure between devices during cycle ergometer exercise in the combined female and male sample.

4.4.2. Treadmill

Means $\pm$ standard deviations (SD) for energy expenditure in (kcal·minute^{-1}) during treadmill exercise are plotted in Figure 14 for the combined group of female and male subjects. A two factor (device x time) repeated measures ANOVA was calculated to assess differences in energy expenditure between measurement devices (respiratory metabolic system and SenseWear® Pro 2 Armband) across exercise stages for the treadmill exercise protocol (Appendix X). A summary of the two factor ANOVA for these data is displayed in figure 14. The ANOVA indicated significant time ($F_{1,23} = 344.019$, $P < 0.001$) and device ($F_{1,23} = 56.888$, $P < 0.001$) main effects. In addition, the time by device interaction effect ($F_{1,23} = 67.469$, $P < 0.001$) was significant. *Post hoc* analysis of the interaction effect indicated that energy expenditure (kcal·minute^{-1}) did not differ between devices for stage 1 of the treadmill protocol. Energy expenditure was significantly lower for the SenseWear® Pro 2 Armband than for the respiratory metabolic system by 0.86 $\pm$ 0.84 kcal·minute^{1} ($P < 0.001$) for stage 2, 2.13 $\pm$ 1.40 kcal·minute^{1} ($P < 0.001$) for stage 3, and 2.97 $\pm$ 1.56 kcal·minute^{1} ($P < 0.001$) for stage 4 respectively (Appendix Y).

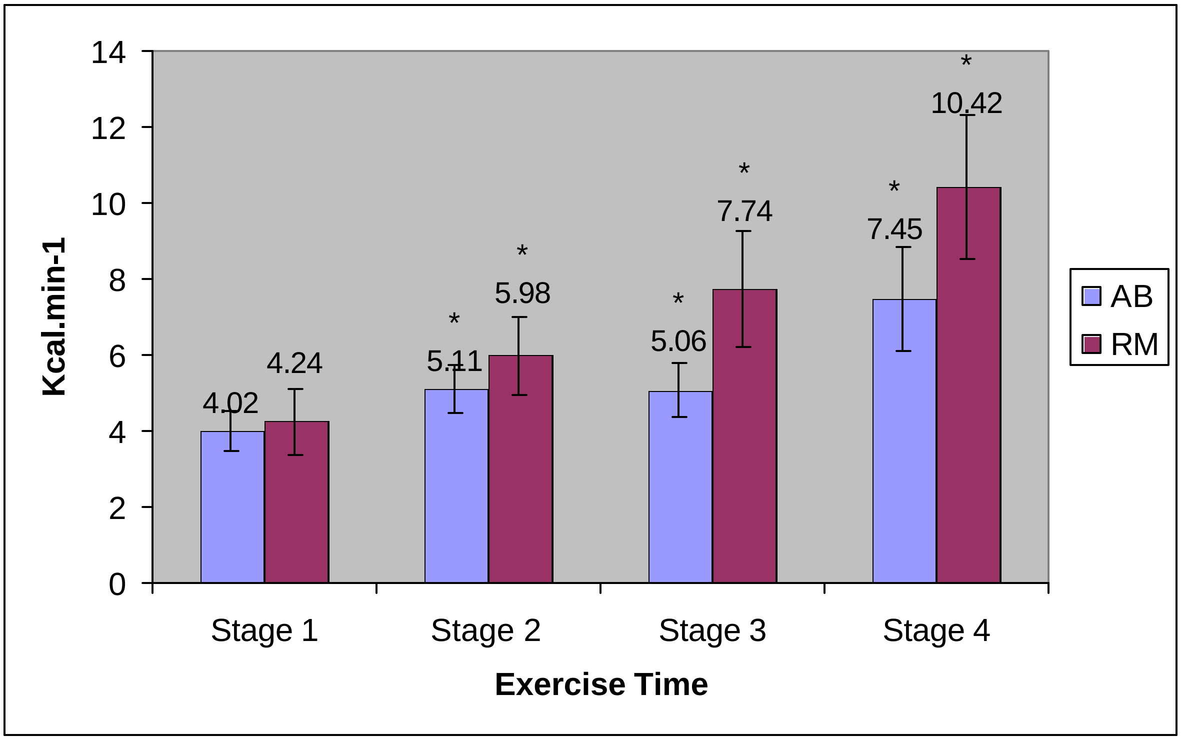


Figure 14: Energy Expenditure (kcal·minute^{-1}) During Treadmill Exercise in the Combined Group of Adolescent Males & Females

***(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system**

The Bland-Altman plots for the combined female and male subjects performing treadmill exercise show a progressive lowering of agreement between the two measuring devices as exercise intensity increases over the four stages (Appendix Z). A representative Bland-Altman plot is presented in figure 15 for stage 1 of the treadmill trial. This plot shows modest agreement between the two measuring devices for energy expenditure.

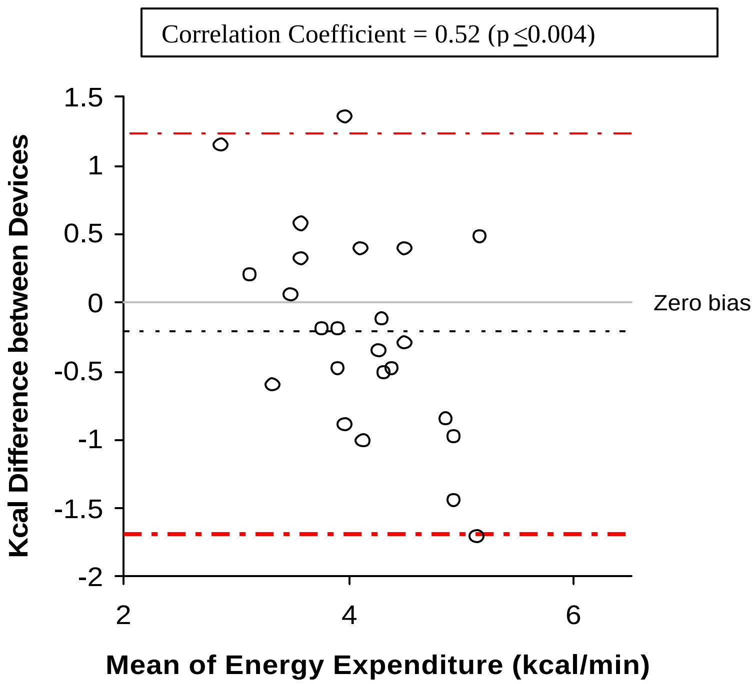


Figure 15: Bland-Altman Plot Treadmill Stage 1 for the Combined Group of Female and Male Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for energy expenditure from each treadmill stage for the respiratory metabolic system and SenseWear® Pro 2 Armband. The intraclass correlations were 0.457 [95% confidence interval (CI): 0.090-0.719] for Stage 1 and 0.354 (CI: -0.080-0.676) for Stage 2, 0.119 (CI: -0.090-0.398) for stage 3, and 0.214 (CI: -0.088-0.567) for stage 4 (Appendix AA).

4.5. Total Energy Expenditure

4.5.1. Cycle Ergometer

Means + standard deviations (SD) for total energy expenditure (total kcals) for females, males, and combined females and males are plotted in Figure 16. Total energy expenditure was calculated as the sum of kcal·minute^{-1} across the cycle ergometer exercise testing trial (i.e. warm up, stage 1, stage 2 and cool down) and was compared between the two devices using a dependent t-test (Appendix BB). The SenseWear® Pro 2 Armband significantly underestimated total energy expenditure by 20.68 $\pm$ 7.86 kcals ($P \leq 0.001$) in females, by 17.41 $\pm$ 6.87 kcals ($P \leq 0.001$) in males, and by 19.11 $\pm$ 7.43 kcals ($P \leq 0.001$) in the combined group.

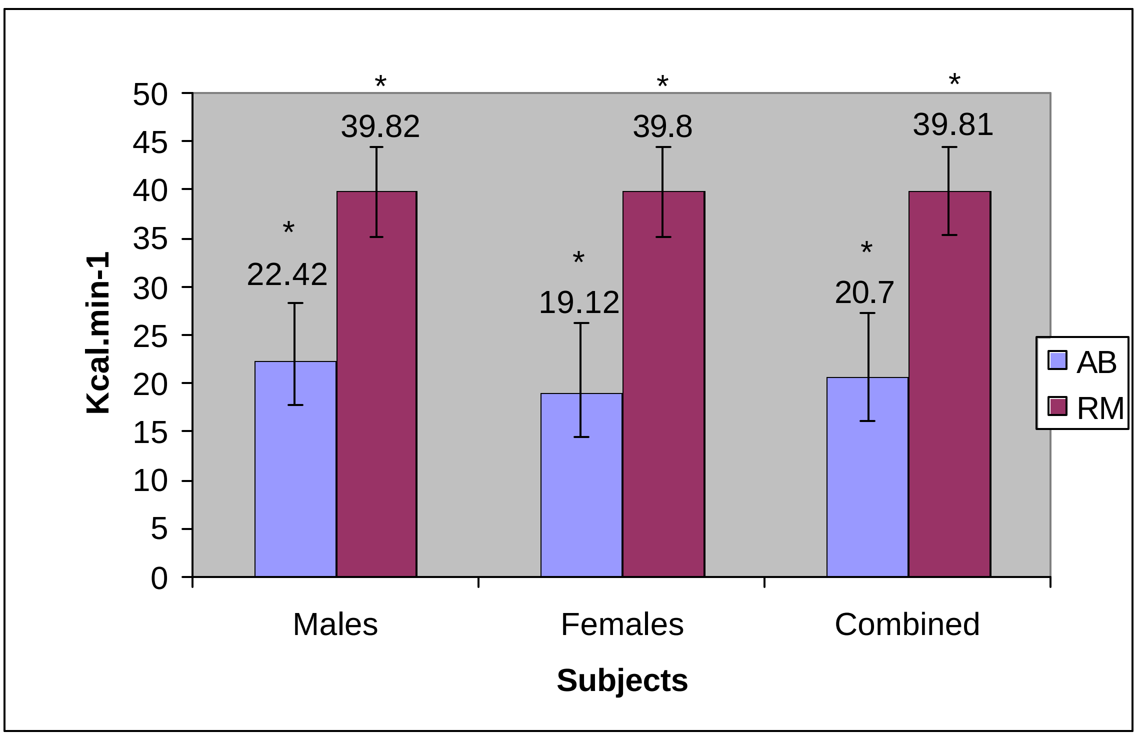


Figure 16: Total Energy Expenditure for Cycle Ergometer Exercise

*(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots were calculated to assess the agreement between devices in measuring total energy expenditure for female, male, and combined female and male groups. A representative Bland-Altman plot of total energy expenditure during cycling ergometer exercise in the female and male combined group is presented in figure 17. The plots for total energy expenditure for females can be found in Appendix F and for males in Appendix J. These plots indicate low agreement between the two devices in measuring total energy expenditure. For the combined group, the plot indicates that the two devices did not agree through the range of mean scores, with the lowest agreement between devices observed for individuals with a mean energy expenditure of 30 total kcals (Figure 17).

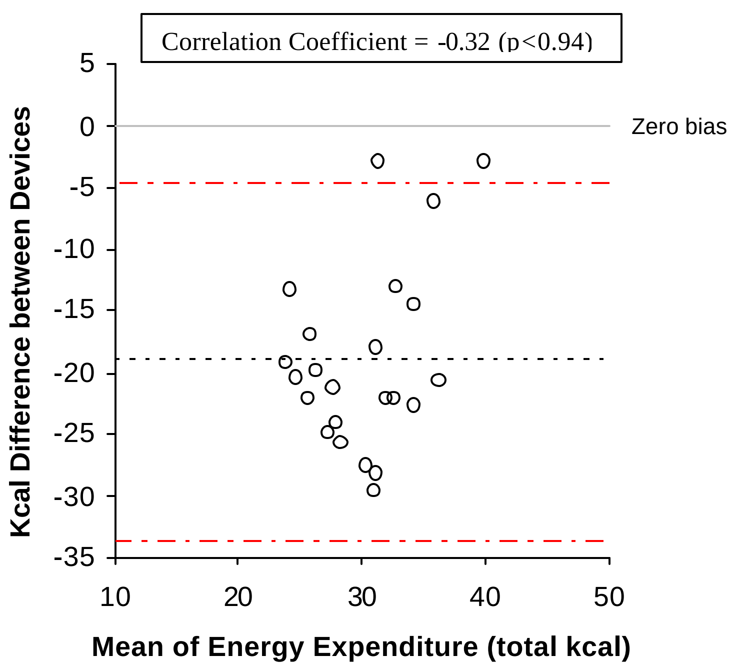


Figure 17: Bland-Altman Plot Total Energy Expenditure (total kcals) During Cycle Ergometer Protocol in the Combined Female and Male Group

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for total energy expenditure for the respiratory metabolic system and SenseWear® Pro 2 Armband (Appendix CC). The intraclass correlation coefficients for total energy expenditure during cycle ergometer exercise were 0.019 [95% (CI): -0.043-0.185] for females, 0.026 [95% (CI): -0.047-0.227] for males, and 0.021 [95% (CI): -0.037-0.134] females and males combined. These low correlations are consistent with the poor agreement observed in the Bland-Altman plots.

4.5.2. Treadmill

Means $\pm$ standard deviations (SD) for total energy expenditure (total kcals) for females, males, and combined female and males are plotted in Figure 18. Total energy expenditure was calculated as a sum of $kcal \cdot minute^{-1}$ across the treadmill exercise trial (i.e. warm up, stage 1, stage 2, stage 3, stage 4, and cool down) and was compared between the two devices using a dependent t-test (Appendix DD). The SenseWear® Pro 2 Armband significantly underestimated energy expenditure by 32.49 $\pm$ 8.58 kcals ($P \leq 0.001$) in females, by 14.82 $\pm$ 14.87 kcals ($P \leq 0.005$) in males, and by 23.66 $\pm$ 14.92 kcals ($P \leq 0.001$) in the combined group.

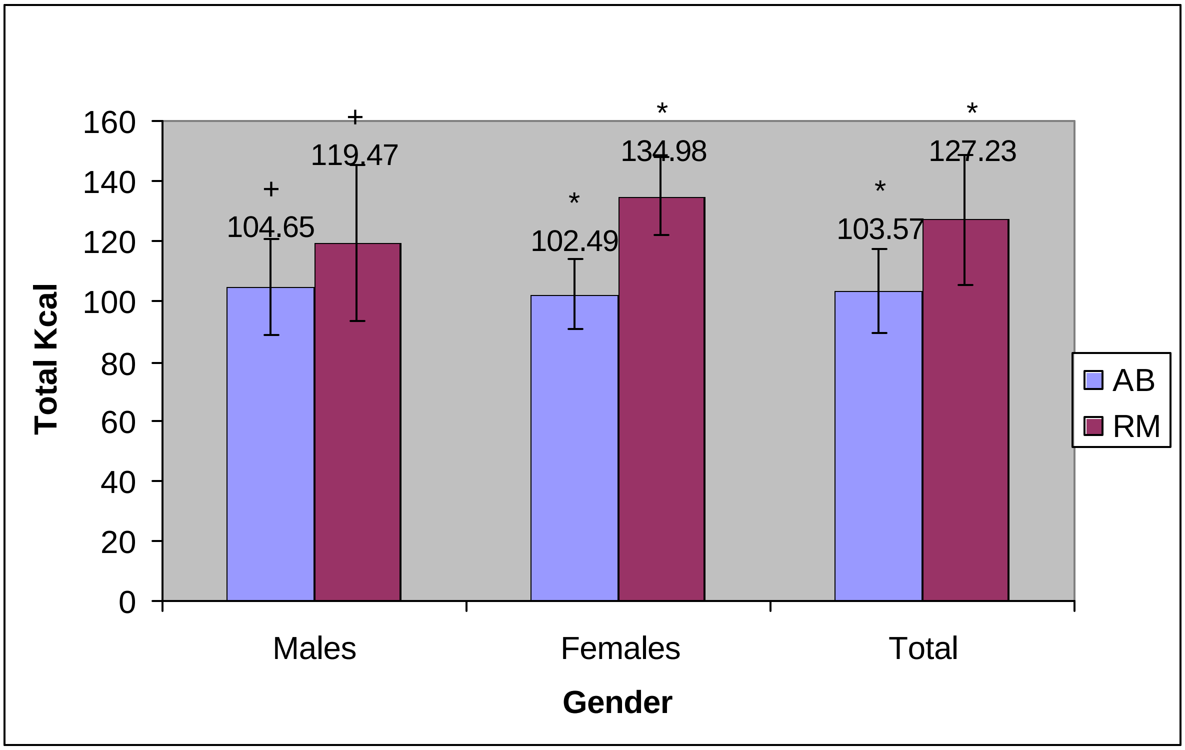


Figure 18: Total Energy Expenditure for Treadmill Exercise Protocol
+(P < 0.005); *(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots were calculated to assess the agreement between devices for measuring total energy expenditure for the female, male, and combined female and male group. In general, the plots indicate low agreement between the two devices in measuring total energy expenditure for treadmill exercise. A representative Bland-Altman plot of total energy expenditure during treadmill exercise in the female and male combined group is presented in figure 19. This plot indicates that the difference between the two devices increased as energy expenditure increased during the walking and jogging treadmill protocol. The Bland-Altman plots for total energy expenditure during treadmill exercise for females can be found in Appendix L and for males in Appendix R.

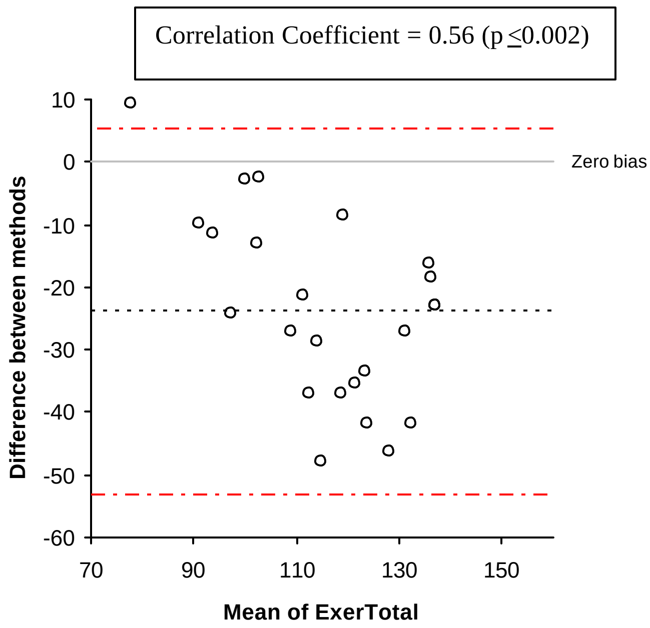


Figure 19: Bland-Altman Plot: Total Energy Expenditure During Treadmill Exercise in the Combined Female & Male Group

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for total energy expenditure for the respiratory metabolic system and SenseWear® Pro 2 Armband (Appendix EE). The intraclass correlation coefficients for total energy expenditure during treadmill exercise were 0.137 [95% (CI): -0.025-0.511] for females, 0.622 [95% (CI): -0.017-0.885] for males, and 0.353 [95% (CI): -0.106-0.710] females and males combined.

4.6. Measure of Resting Energy Expenditure

4.6.1. Female Subjects

Means + standard deviations (SD) for resting energy expenditure are plotted in kcal · minute^{-1} (Figure 20) and total kcals (Appendix FF) during the cycle ergometer trial for female subjects. A dependent t test was computed to assess differences in the resting energy expenditure response between measurement devices (respiratory metabolic system versus SenseWear® Pro 2 Armband). Prior to the cycle ergometer trial, the dependent t test indicated the SenseWear® Pro 2 Armband significantly underestimated resting energy expenditure when values were expressed as both kcal·minute^{-1} (0.26 + 0.20, p< 0.001) and total kcals (1.30 + 1.02, p < 0.001) (Appendix GG).

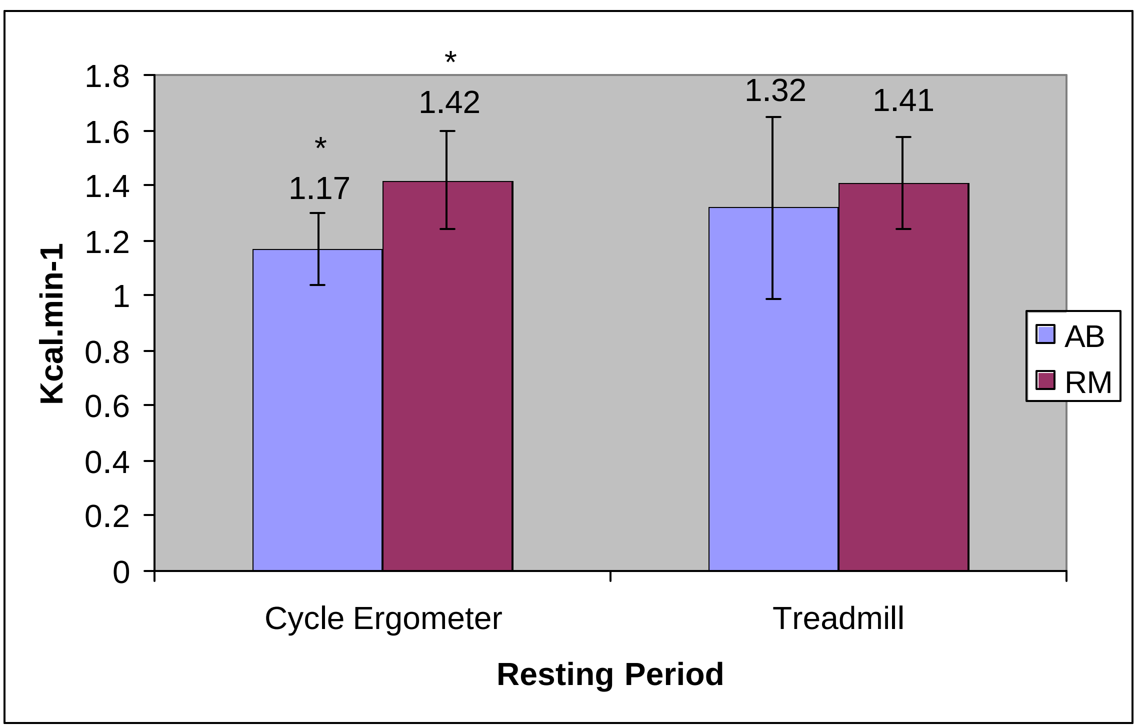


Figure 20: Resting Energy Expenditure Prior Exercise in Female Subjects

*(P < 0.001) AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Means ± standard deviations (SD) for resting energy expenditure are plotted in kcal·minute^{-1} (Figure 20) and total kcals (Appendix FF) prior to the treadmill trial for female subjects. The dependent t tests indicated that there were no significant differences between the measuring devices for resting energy expenditure when values were expressed as both kcal·minute^{-1} (0.10 ± 0.29, p=0.267) and for the total resting period (0.48 ± 1.43, p =0.267) (Appendix GG).

Bland-Altman plots were calculated to assess the agreement between devices for measuring to resting energy expenditure. A representative Bland-Altman plot of resting energy expenditure prior to the cycle ergometer protocol in the female subjects is presented in figure 21. This plot indicated modest agreement in measures of resting energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system. The plot for the resting energy expenditure period prior to the treadmill protocol can be found in Appendix HH. This Bland-Altman plot indicated good agreement in the resting energy expenditure data measured by the two devices prior to the treadmill protocol.

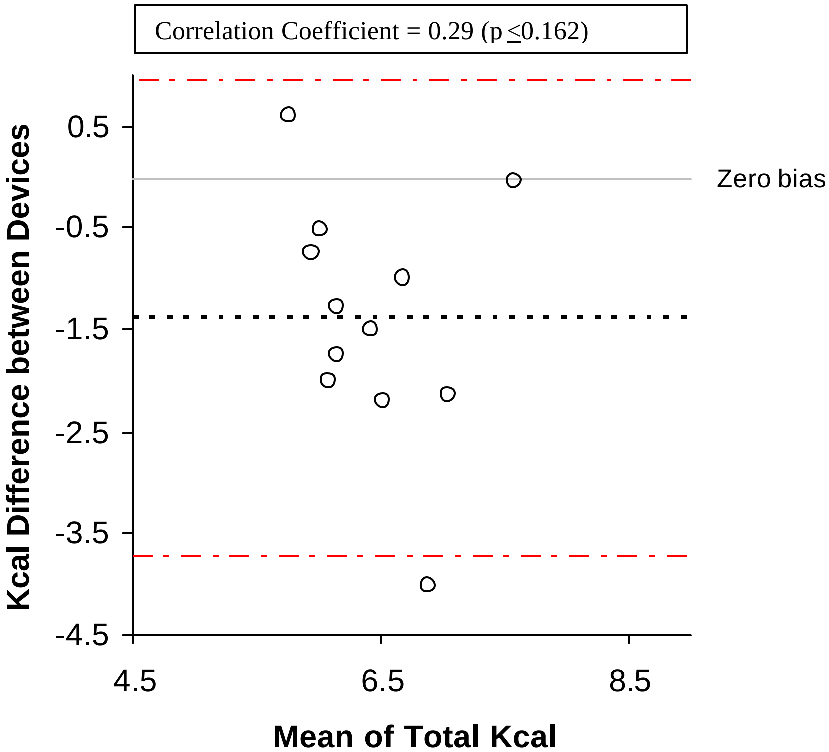


Figure 21: Bland-Altman Plot Resting Energy Expenditure Prior Cycle Ergometer Exercise in Female Subjects

Kcal difference between devices= Energy expenditure in $kcal \cdot min^{-1}$ from Respiratory metabolic system minus energy expenditure in $kcal \cdot min^{-1}$ from SenseWear Pro 2 Armband; **Mean Energy Expenditure ($kcal \cdot min^{-1}$)**= Energy expenditure in $kcal \cdot min^{-1}$ from Respiratory metabolic system minus energy expenditure in $kcal \cdot min^{-1}$ from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for resting energy expenditure data from the respiratory metabolic system and SenseWear® Pro 2 Armband. The intraclass correlations were 0.060 [95% confidence interval (CI): -0.139-0.414] for the resting period prior to the cycle ergometer protocol and 0.400 [95% confidence interval (CI): -0.161-0.776] for the resting period prior to the treadmill protocol (Appendix II).

4.6.2. Male Subjects

Means ± standard deviations (SD) for resting energy expenditure are plotted in kcal·minute^{-1} (Figure 22) and total kcals (Appendix JJ) during the cycle ergometer for male subjects. Dependent t tests were computed to assess differences in resting energy expenditure prior to cycle exercise between the SenseWear® Pro 2 Armband and respiratory metabolic system (Appendix KK). There were no significant differences in resting energy expenditure data prior to the cycle trial for male subjects (0.001 ± 0.48 kcal·minute^{-1}; $P < 0.990$ and 0.001 ± 2.38 total kcals; $P < 0.990$).

Means ± standard deviations (SD) for resting energy expenditure are plotted in kcal·minute^{-1} (Figure 22) and total kcals (Appendix JJ) during the treadmill trial for male subjects. Dependent t tests were computed to assess differences in resting energy expenditure prior to treadmill exercise between the SenseWear® Pro 2 Armband and respiratory metabolic system (Appendix KK). There were no significant differences in resting energy expenditure prior to the treadmill trial for male subjects (mean difference ± SD 0.10 ± 0.29 kcal·minute^{-1} ($P < 0.267$) and 0.48 ± 1.43 total kcals; $P < 0.267$).

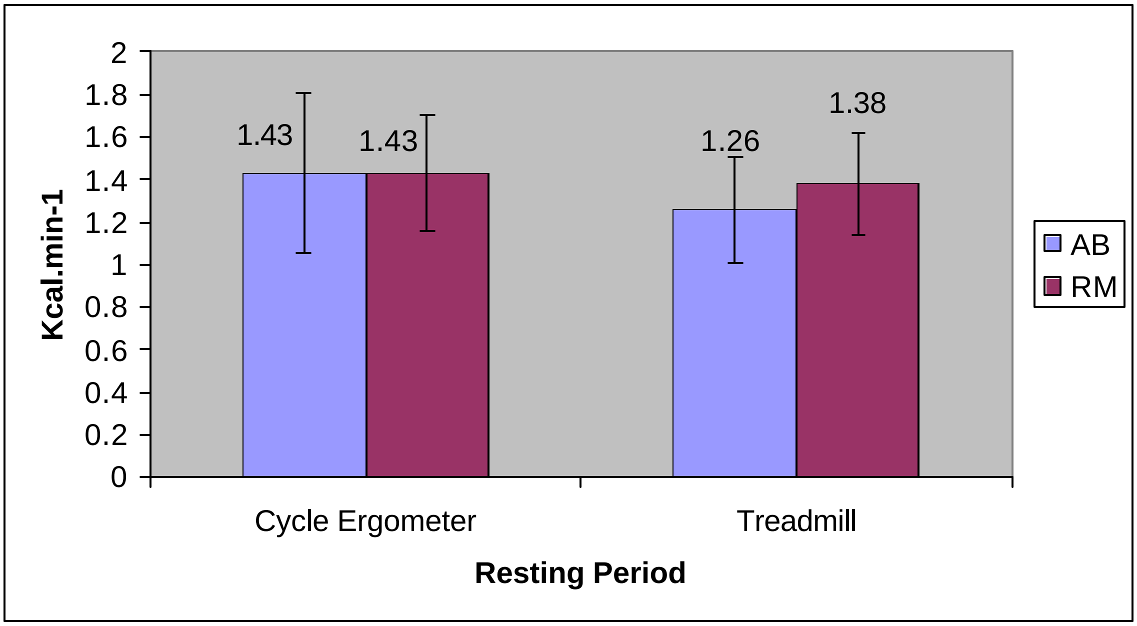


Figure 22: Resting Energy Expenditure Prior Exercise in Male Subjects

AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots were calculated to assess the agreement between devices for measuring to resting energy expenditure. A representative Bland-Altman plot of resting energy expenditure prior to the cycle ergometer protocol in the male subjects is presented in Figure 23. This plot indicated good agreement in measures of resting energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system. The plot for the resting energy expenditure period prior to the treadmill protocol can be found in Appendix LL. This Bland-Altman plot also indicated good agreement in the resting energy expenditure data measured by the two devices prior to the treadmill protocol.

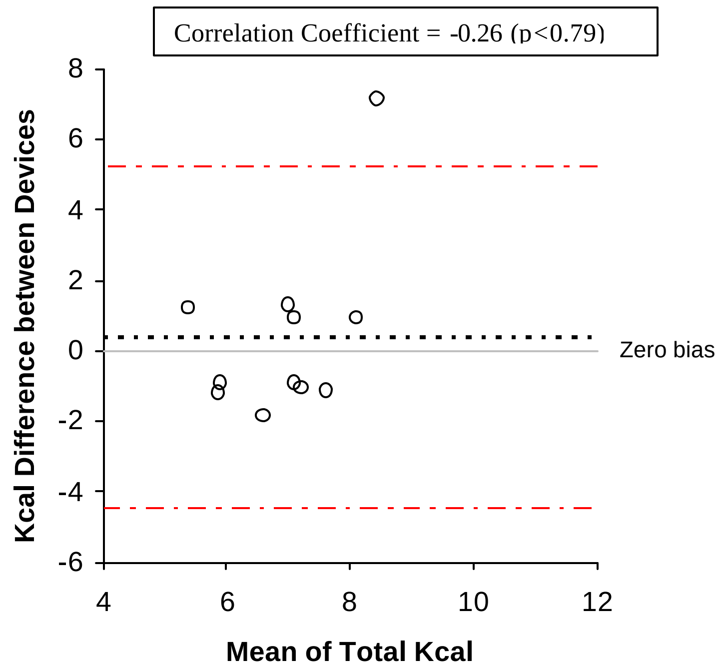


Figure 23: Bland-Altman Plot Resting Energy Expenditure Prior Cycle Ergometer Exercise in Male Subjects

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for resting energy expenditure data from the respiratory metabolic system and SenseWear® Pro 2 Armband. The intraclass correlations were -0.37 [95% confidence interval (CI): -0.700-0.576] for the resting period prior to the cycle ergometer protocol and 0.490 [95% confidence interval (CI): -0.023-0.814] for the resting period prior to the treadmill protocol (Appendix MM).

4.6.3. Female & Male Subjects Combined

Means ± standard deviations (SD) for resting energy expenditure are plotted in kcal·minute^{-1} (Figure 24) and total kcals (Appendix NN) prior to the cycle ergometer trial for all subjects. Dependent t tests were computed to assess differences in resting energy expenditure between measurement devices (respiratory metabolic system versus SenseWear® Pro 2 Armband) (Appendix OO). There were no significant differences in resting energy expenditure prior to the cycle ergometer trial for male subjects (mean difference ± SD 0.15 ± 0.37 kcal·minute^{-1} ; $P < 0.064$ and by 0.76 ± 1.87 total kcals; $P < 0.064$).

Means ± standard deviations (SD) for resting energy expenditure are plotted in kcal·minute^{-1} (Figure 24) and total kcals (Appendix NN) prior to the treadmill trial for all subjects. Dependent t tests were computed to assess differences in resting energy expenditure between measurement devices (respiratory metabolic system versus SenseWear® Pro 2 Armband) (Appendix OO). There were no significant differences in resting energy expenditure prior to the treadmill trial for the combined female and male group (mean difference ± SD 0.11 ± 0.26 kcal·minute^{-1} $P < 0.054$ and by 0.54 ± 1.30 total kcals; $P < 0.054$).

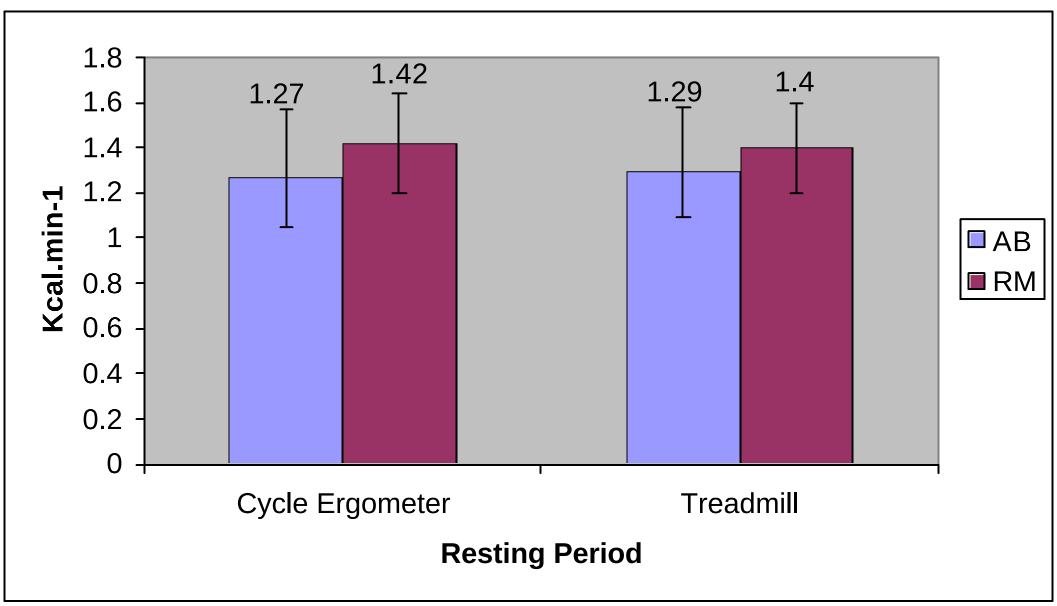


Figure 24: Resting Energy Expenditure in a Combined Group of Female and Male Subjects

AB= SenseWear® Pro 2 Armband; RM=Respiratory metabolic system

Bland-Altman plots were calculated to assess the agreement between devices for measuring to resting energy expenditure. A representative Bland-Altman plot of resting energy expenditure prior to the cycle ergometer protocol in the combined female and male sample is presented in figure 25. This plot indicated good agreement in measures of resting energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system. The plot for the resting energy expenditure period prior to the treadmill protocol can be found in Appendix PP. This Bland-Altman plot also indicated good agreement in the resting energy expenditure data measured by the two devices prior to the treadmill protocol.

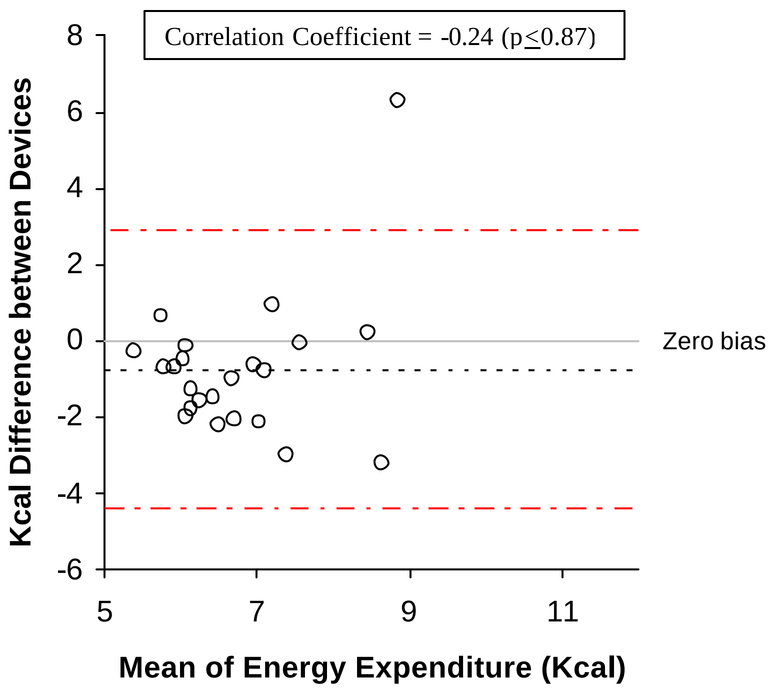


Figure 25: Bland-Altman Plot Resting Energy Expenditure Prior Cycle Ergometer Exercise in the Combined Female and Male Sample

Kcal difference between devices= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband; **Mean Energy Expenditure (kcal·min^{-1})**= Energy expenditure in kcal·min^{-1} from Respiratory metabolic system minus energy expenditure in kcal·min^{-1} from SenseWear Pro 2 Armband divided by 2; **Zero Bias**= The line representing no difference between measuring devices; **Red dashed lines**= 95% Confidence Interval; **Black dashed line**= Mean difference between devices

Intraclass correlation coefficients were computed for resting energy expenditure data from the respiratory metabolic system and SenseWear® Pro 2 Armband. The intraclass correlations were -0.006 [95% confidence interval (CI): -0.340-0.382] for the resting period prior to the cycle ergometer protocol and 0.436 [95% confidence interval (CI): 0.073-0.704] for the resting period prior to the treadmill protocol (Appendix MM).

5. CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. INTRODUCTION

The primary purpose of this investigation was to examine the validity of the SenseWear® Pro 2 Armband to assess energy expenditure during various modes of physical activity in adolescent subjects. It was hypothesized that measures of energy expenditure during treadmill and cycle ergometer exercise would not differ between the SenseWear® Pro 2 Armband and the criterion respiratory metabolic system when compared for female and male subjects, separately and when combined as a group.

The present study is the first to examine the validity of the SenseWear® Pro 2 Armband to measure energy expenditure in adolescent females and males. Three previous studies have examined the validity of the SenseWear® Pro 2 Armband to measure energy expenditure in adults in the laboratory setting. These studies indicate both consistencies and inconsistencies in the research findings when compared to the present investigation.

The primary finding of this investigation is that the SenseWear® Pro 2 Armband generally underestimated energy expenditure during cycle ergometer and treadmill exercise in adolescent females and males. There are several mechanisms that may explain the underestimation of energy expenditure across the modes of exercise tested. First, the SenseWear® Pro 2 Armband employed generalized algorithms for both resting and physical activity energy expenditure that were developed using adult formulas for estimating energy expenditure. These algorithms were evaluated and revised based on testing exclusively with adult subjects. Using these adult based formulas and algorithms to predict energy expenditure in adolescents may increase the likelihood of error in energy expenditure estimations. Another mechanism to examine is the use of a two-axis accelerometer to provide movement signals to the energy prediction model employed by the SenseWear® Pro 2 Armband. In the literature, it has been well documented that the accelerometers underestimate energy expenditure during non-weight bearing exercise and when exercise is performed on an inclined surface. In addition, the armband does not detect the beginning, end and type of physical activity being performed and this lack of contextual identification decreases the accuracy of the energy expenditure calculation. These and other mechanisms will be examined more closely as they relate to the underestimation of energy expenditure during the specific exercise mode tested.

5.2. VALIDITY OF THE SENSEWEAR PRO 2 ARMBAND IN CYCLE ERGOMETER EXERCISE

One of the primary findings of this investigation was that the SenseWear® Pro 2 Armband significantly underestimated energy expenditure during cycle ergometer exercise compared to the respiratory metabolic system in both female and male adolescent subjects. Significant lower energy expenditure was found for the separate groups of females and males at both cycle ergometer exercise stages when measurements were made with the SenseWear® Pro 2 Armband. In addition, the SenseWear® Pro 2 Armband significantly underestimated energy expenditure when male and female subjects were combined. Intraclass correlations relating energy expenditure (kcal·min-1) from the two devices for the cycle ergometer exercise stages were low for females, males, and females and males combined. These low correlations are consistent with the poor agreement between measuring devices observed in the Bland-Altman plots for cycle ergometer exercise.

The present findings do not support the research hypothesis that measures of energy expenditure would not differ between the SenseWear® Pro 2 Armband and respiratory metabolic system when compared separately for female and male subjects. In addition, for the cycle ergometer protocol, these findings do not support the research hypothesis that measures of energy expenditure would not differ between the SenseWear® Pro 2 Armband and respiratory metabolic system when a combined sample of female and male adolescents were examined. Since energy expenditure was consistently lower when measured by the SenseWear® Pro 2 Armband for females, males, and the combined group for the cycle ergometer protocol, the results will be discussed collectively across gender.

The cycle ergometer exercise findings from this study are consistent with the results from a previous study involving adults that compared energy expenditure between the SenseWear® Pro 2 Armband and a respiratory metabolic system. In a study by Jakicic et al., the SenseWear® Pro 2 Armband significantly underestimated energy expenditure during cycle ergometer exercise for both low and moderate intensity exercise [71]. The Bland-Altman plot for cycle ergometer exercise confirmed the low agreement between measuring devices and indicated that the greatest difference occurred as energy expenditure increased. It was concluded that the generalized algorithms that are standard in the commercial version of the armband might be less accurate exercise specific algorithms [71].

In another study, Fruin et al. found no significant differences between the SenseWear® Pro 2 Armband and indirect calorimetry measurements of energy expenditure at three different time periods (early, mid, and late) and for total energy expenditure during a 40 minute cycle ergometer trial [72]. The greatest variation in energy expenditure occurred during the early time period (8.8% difference, $P \geq 0.07$). Although the differences in energy expenditure between devices were not statistically significant, the Bland-Altman plots showed low limits of agreement between the two devices with larger prediction error seen for individuals with the highest and lowest energy expenditures. It was concluded that the SenseWear® Pro 2 Armband provided a close estimate of cycling exercise energy expenditure in groups but may not be suitable for an individual estimate.

Comparing these two adult studies with the present investigation in adolescent subjects, all three studies showed poor agreement in measures of energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system as observed by the Bland-Altman plots. However, the SenseWear® Pro 2 Armband significantly underestimated energy expenditure responses during cycle ergometer exercise in only one of the adult and the present investigation with adolescents. In the second adult study, there were no significant differences in measures of energy expenditure between devices for adult female and male subjects in cycle ergometer exercise. Therefore, the findings from this investigation are consistent and inconsistent with the results from the previous adult studies using the SenseWear® Pro 2 Armband.

5.2.1. Mechanisms for Underestimation of Energy Expenditure during Cycle Ergometer Exercise

When the present findings are examined in conjunction with previous reports, in general the SenseWear® Pro 2 Armband underestimates energy expenditure for both adolescents and adults performing cycle ergometer exercise. There are several mechanisms that may explain the lower energy expenditure estimates derived from the SenseWear® Pro 2 Armband.

5.2.1.1. Generalized Algorithms

The SenseWear® Pro 2 Armband had difficulty detecting when a specific exercise starts and stops as well as determining the specific type of activity being performed (i.e. contextual detection). For example, the armband has difficulty distinguish body movement required during cycling from movement involved during walking. Since there is inadequate contextual detection of specific activities, the physiological sensors all work and/or contribute the same towards the calculation of energy expenditure. In essence, the armband treats all physical activity the same, using the generalized algorithms to predict physical activity energy expenditure for all activities. This is problematic since certain physical activities such as running, involve locomotion where a primary dependence on the accelerometer signal is appropriate. In contrast, for non-weight bearing activities, it may be important to have comparatively more emphasis on signals from other physiological sensors (GSR or heat flux) that are not dependent on body weight displacement and/or site-specific movement. Previous studies have confirmed that the relation between accelerometer count and energy expenditure is specific to the activity being performed [40]. Therefore, information about the type of activities being performed is necessary to accurately estimate energy expenditure using a device such as the SenseWear® Pro 2 Armband that appears to place a disproportionate emphasis on accelerometer detection of body weight displacement.

Jakicic et al. found that when proprietary exercise-specific algorithms were applied to their data, the energy expenditure estimation improved [71]. That is, when exercise specific algorithms were used, there were no significant differences in total energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system for walking, cycling, stair stepping, and arm cranking. However, there are practical issues related to using activity-specific prediction equations. If the individual user needs to manually select an activity-specific algorithm each time they engage in a different activity, the procedure could prove cumbersome. Alternatively, if exercise specific algorithms can be built into the armband device and accompanying software without relying on frequent user input, the use of activity monitors may be more effective in estimating energy expenditure in the free living environment.

It is important to note that exercise specific algorithms were not available for the present investigation. The intent was to examine the validity of the commercially available (generalized) algorithms in the SenseWear® Pro 2 Armband. It is proposed that data from this investigation will assist BodyMedia in developing exercise specific algorithms for adolescents that are a standard feature for the armband system.

5.2.1.2. Accelerometer Technology

Historically, accelerometers have had difficulty estimating energy expenditure in non-locomotor and/or non-weight bearing exercise [4, 36]. This may in part be due to the inability of the accelerometer to register energy expenditure that requires little or no movement at the location of the monitor. The monitor must be moving to register activity. Accelerometer output is influenced by the place of attachment to the body [73]. Body sites are differentially active, depending on the activity type and movement of other anatomical regions. In addition, non-weight bearing activities such as cycling require little vertical acceleration/deceleration movement, contributing to the underestimation of energy expenditure during these activities [36].

Campbell et al. reported that the Tritrac significantly underestimated energy expenditure compared to the criterion respiratory metabolic system for two non-weight bearing activities [38]. Percent differences in energy expenditure between the two systems during arm ergometry and stationary cycling were 65% and 53%, respectively. "In this investigation, stationary cycling was underestimated by the Tritrac presumably because movement at the hip was limited, despite the fact that the energy expenditure was actually quite high [38]." These observations by Campbell et al.. may add to the explanation of why the SenseWear® Pro 2 Armband underestimated energy expenditure during cycling exercise in the current investigation. The armband was worn on the upper right arm and subjects were informed to position their hands on the cycle handlebars throughout the test. Thus, there was little movement of the upper body, especially the arms, during the cycle ergometer protocol. When examining the InnerView Software data output, the accelerometer step count for cycling exercise recorded zero in most subjects. If the accelerometer signal has the greatest weighting in the energy prediction model, the fact that step movements were not recorded during cycling exercise likely contributed to the underestimation of the energy expenditure.

Historically, accelerometer methodology has had difficulty distinguishing between sedentary states and both very low and low intensity activities [62, 74]. Nichols et al. reports "it is likely that the Tritrac cannot discriminate between sedentary and very light activities and therefore underestimates very light activity [74]." Similarly, Chen et al. found the Tritrac accelerometer significantly underestimated energy expenditure for light intensity and sedentary activities. "The major underestimation was in the low intensity activities of less than or equal to 4 METs [62]." The cycle ergometer protocol in the present investigation was classified as low intensity (~ 4 METs) exercise. The inability of the accelerometer in the SenseWear® Pro 2 Armband system to accurately estimate energy expenditure at this low intensity exercise may have related to the comparatively low movement involved or to the movement of body parts (such as the legs) other than where the monitor was positioned (upper right arm) during the cycle ergometer exercise.

In general, accelerometers and other similar motion monitors underestimate energy expenditure for activities with large force:displacement ratio such as stair climbing and knee bends [3]. The energy expenditure required for the necessary force production in these types of activities is greater than the resulting displacement measured by the motion sensors. On the other hand, these monitors overestimate energy expenditure for activities with a small force:displacement ratio such as jumping and running, as there is excessive movement compared with the force generated. If energy cost of an activity is related to muscular loading using isometric contractions, upper body movement, added weight bearing (carrying, lifting, pushing, etc) or inclined or soft surfaces, it will likely not be reflected by an increase in accelerometer counts [40]. By extension, it is probable that the comparatively limited movement recorded by the SenseWear® Pro 2 Armband during the cycle ergometer protocol was not proportional to actual energy expenditure required to perform the external work, thus contributing to the underestimation of energy expenditure.

5.2.1.3. Body Heat Sensor Input

Given the limitations of an accelerometer to accurately measure the energy cost of non-weight bearing exercise, it would be logical for the SenseWear® Pro 2 Armband to rely more heavily on the body heat sensors. However, there are limitations with body heat monitoring as well. There is a delayed response between when the heat is produced during exercise and when the monitor detects the change in body temperature. Of the two body heat sensors in the SenseWear® Pro 2 Armband, the heat flux sensor responds more rapidly than the GSR, which is delayed by several minutes [2]. BodyMedia reports that the body heat sensors provide more appropriate data in protocols lasting eight minutes or longer [2]. Since the protocol in the current study used four minutes exercise stages, this may not have given the body heat sensors enough time to provide data indicative of metabolic heat production by muscle. In addition, the cycle ergometer protocol was classified as a low intensity exercise. Less body heat is generated during lower intensity exercise. Given the delay in response to the body heat sensors and the lower body heat generated during low intensity exercise, input from the body heat sensors may not have reflected the actual energy cost associated with the cycle ergometer exercise.

For cycle ergometer exercise, the SenseWear® Pro 2 Armband clearly underestimates energy expenditure when comparisons are made for adolescent females and males. Developing algorithms customized for adolescents along with exercise specific algorithms that are initiated at the onset of exercise, may prove beneficial in reducing the estimation error observed in the SenseWear® Pro 2 Armband's measures of energy expenditure during cycling exercise.

5.3. VALIDITY OF THE SENSEWEAR PRO 2 ARMBAND IN TREADMILL EXERCISE

Another primary finding of this investigation was that the SenseWear® Pro 2 Armband significantly underestimated energy expenditure compared to the respiratory metabolic system during most of the treadmill exercise stages in adolescent female and male subjects. Significant differences in energy expenditure were found in females during all four stages of the treadmill protocol. For male subjects, measures of energy expenditure from the SenseWear® Pro 2 Armband and respiratory metabolic system were not significantly different during stage 1 and 2 of the treadmill protocol. However, energy expenditure measures for SenseWear® Pro 2 Armband were significantly lower during stage 3 and 4. When male and female subjects were combined, the SenseWear® Pro 2 Armband significantly underestimated energy expenditure during stages 2, 3, and 4.

These findings do not support the research hypothesis that measures of energy expenditure would not differ between the SenseWear® Pro 2 Armband and respiratory metabolic system when compared separately for adolescent female and male subjects. In addition, these findings do not support the research hypothesis that measures of energy expenditure would not differ between the SenseWear® Pro 2 Armband and respiratory metabolic system when a combined sample of female and male adolescents was examined. Since the pattern of energy expenditure differences between measuring devices was not consistent for females and males during the treadmill protocol, mechanisms explaining these differences will be discussed according to gender.

5.3.1. Level Treadmill Walking

In female subjects, there were significant differences in the measures of energy expenditure ($kcal \cdot min^{-1}$) between the SenseWear® Pro 2 Armband and the respiratory metabolic system during level treadmill walking at both the 3.0 mph, 0% grade (stage 1) and 4.0 mph, 0% grade (stage 2) stages. The SenseWear® Pro 2 Armband underestimated energy expenditure by 13% during stage 1. The percent difference increased to 20% during stage 2. The Bland-Altman plots indicate low agreement between devices for estimating energy expenditure, with larger prediction error found for individuals with the highest energy expenditure.

On the other hand, there were no significant differences in energy expenditure ($kcal \cdot min^{-1}$) measures between the SenseWear® Pro 2 Armband and the respiratory metabolic system for the two level treadmill walking stages in adolescent male subjects. That is, during stages 1 and 2, the armband differed only by 7% and 5% respectively from the respiratory metabolic system.

The Bland-Altman plots confirm the good agreement for measures of energy expenditure between devices.

When males and females were combined (n=24), the differences observed separately in female and male adolescents were divided. The SenseWear® Pro Armband measures of energy expenditure were significantly different from the respiratory metabolic system during stage 2, but not for stage 1. Energy expenditure measures differed between measuring devices by only 2% in stage 1 and 13% in stage 2. As observed in the Bland-Altman plots, there was modest agreement in energy expenditure measures between the SenseWear® Pro 2 Armband and the respiratory metabolic system.

The present study involving adolescents is not consistent with those of the three previous adult studies where energy expenditure was measured with the SenseWear® Pro Armband during treadmill exercise. Jakicic et al. reported that the armband overestimated energy expenditure of level treadmill walking at 3.0 mph (1.3 $\pm$ 0.5 kcal·min^{-1}) in 40 adult men and women combined [71]. Fruin et al. found similar results. The SenseWear® Pro Armband overestimated level walking on the treadmill by 38% at 3.0 mph and by 14% at 4.0 mph [72]. In the third study, King et al. examined the validity of the SenseWear® Pro Armband to measure energy expenditure in 19 adults (9 males and 10 females) while walking/running at seven different speeds on the treadmill [75]. Investigators found that each subsequently faster speed elicited a significant increase in mean energy expenditure for the SenseWear® Pro Armband and the respiratory metabolic system. However, the SenseWear® Pro Armband systematically overestimated energy expenditure at all seven speeds.

5.3.1.1. Mechanisms for the Underestimation of Energy Expenditure during Level Treadmill Walking

The direction of differences in energy expenditure measures between the SenseWear® Pro 2 Armband and the respiratory metabolic system for level treadmill walking varied among adolescent females and males examined presently and adult subjects used in previous investigations. In all three studies using adult subjects, the SenseWear® Pro 2 Armband overestimated the energy expenditure of level treadmill walking. In adolescent males, the armband measures of energy expenditure were not significantly different from the respiratory metabolic system. In adolescent females, however, the SenseWear® Pro 2 Armband significantly underestimated energy expenditure compared to the respiratory metabolic system. The mechanisms related to the underestimation of energy expenditure by the SenseWear® Pro 2 Armband in females during level treadmill walking are discussed below.

Accelerometer Technology: In general, accelerometry methods do not account for stride length changes as walking speed varies, leading to underestimation of energy expenditure, especially at higher speeds [4]. Stride length and stride frequency are the primary components of walking/running velocity [76]. As speed increases, there is a corresponding increase either in stride length, in stride frequency or in a combination of both [77]. Accelerometers count step (or stride) frequency. Thus if an individual increases walking speed by predominantly increasing stride length, the accelerometer will not be able to accurately detect the increased energy expenditure associated with the increase in speed [78]. This will lead to underestimation of energy expenditure.

Yngve et al. suggested that because activity counts are a function of vertical acceleration and the frequency of this acceleration, a possible difference in gait might produce differences in accelerometer output [73]. Kerrigan reported that when normalized for height, females tend to have the same or slightly greater stride lengths than males [79]. If the accelerometer signal has the greatest weighting in the SenseWear® Pro 2 Armband energy prediction model, then changes in stride length and the associated increase in energy expenditure may not be accounted for due to the limitation in accelerometry technology. This may have contributed to the underestimation of energy expenditure by the SenseWear® Pro 2 Armband during level treadmill walking in female adolescents.

There are anatomical factors related to movement during walking that may impact the accuracy of the accelerometer to record body acceleration and thus estimate energy expenditure. "When walking, women exhibit comparatively more motion of the pelvis in the coronal plane (from the nose to the back of the head) and less vertical center of mass motion displacement. It is possible that women use greater pelvic motion in the coronal plane to reduce their vertical center of mass displacement" [80]. Chen et al. confirmed that when walking, females have a "smaller parameter in the vertical plane in accelerometers (than males)" [62]. In part, this may be attributable to the fact that females have wider hips than males, which makes the femur more pronounced and lowers the center of gravity [81]. A reduction in the vertical movement during walking may reduce the body movement in the vertical plane that is detected by the accelerometer, thus decreasing the accelerometer output count. Reduced accelerometer counts lead to lower predictions of energy expenditure. If the signal in the two-axis accelerometer of the SenseWear® Pro 2 Armband carries the greatest weight in the energy prediction model, then reduced movement detected in the vertical plane will contribute to an underestimate of energy expenditure.

Body Composition: Lean body mass, fat mass and total body weight influence total energy expenditure especially during locomotor activities [82]. Therefore, it can be assumed that these variables will also influence physical activity monitors that predict energy expenditure. In general, both adolescent and adult males have a higher percentage of lean body mass and less body fat than females [81]. In the present investigation, the adolescent males averaged 12 % body fat whereas, adolescent females averaged 28% body fat. The greater body fat in females may have delayed the release of body heat during exercise [81]. When body heat transfer to the skin is delayed, the skin temperature will not reflect the metabolic heat production of the exercising muscle. As a result, the signal from the heat flux and temperature sensors in the SenseWear® Pro 2 Armband may not have accurately reflected the heat production (energetic cost) of the working muscle(s), and thus underestimated the true energy expended by the body.

In addition, females have comparatively more adipose tissue in the upper arms [83]. The female subjects in this investigation had significantly higher triceps skinfold measures compared to male subjects (see Table 1, Chapter 3, Methods). The SenseWear® Pro 2 Armband is worn on the upper right arm. The presence of more fat in the upper arm, may make it harder to dissipate heat from the subcutaneous level to the skin level. This too may have lowered the signal from the SenseWear® Pro 2 Armband's skin temperature and GSR sensors resulting in an underestimation of physical activity energy expenditure.

Activity induced energy expenditure is a function of the body acceleration and the mass of the body displaced [84]. A greater body mass corresponds to a net higher energy cost of work during weight bearing activity [81]. In this investigation, the average weight of female subjects was seven kilograms higher than the average weight of male subjects. The energy cost of walking is proportional to body weight [82]. Since the SenseWear® Pro 2 Armband's algorithms are proprietary, it is unclear how body weight is used as a determinant in the model to estimate energy expenditure during weight-bearing physical activity.

5.3.2. Incline Treadmill Walking/Jogging

Unlike level treadmill walking, the pattern of energy expenditure differences between the SenseWear® Pro 2 Armband and the respiratory metabolic system were consistent for adolescent males, females, and adults during graded treadmill walking/jogging. In female subjects, there were significant differences in the measures of energy expenditure between devices during graded treadmill walking/jogging at both the 4.0 mph, 5% grade (stage 3) and the 4.5 mph, 5% grade (stage 4) stages. The SenseWear® Pro 2 Armband underestimated energy expenditure by 34% during stages 3 and 4. The Bland-Altman plots indicated a low agreement in measures of energy expenditure between the SenseWear® Pro 2 Armband and the respiratory metabolic system during graded treadmill walking/jogging in adolescent females. In general, the magnitude of difference increased as energy expenditure increased.

For male subjects, there were significant differences in the measures of energy expenditure between devices during graded treadmill walking/jogging at both the 4.0 mph, 5% grade (stage 3) and the 4.5 mph, 5% grade (stage 4) stages. The SenseWear® Pro 2 Armband underestimated energy expenditure by 16% during stage 3 and 21% during stage 4. Using the Bland-Altman plots it was noted that the magnitude of difference between measures of energy expenditure for the two devices increased as energy expenditure increased during graded treadmill walking/jogging in the adolescent male subjects.

When males and females were combined (n=24), the SenseWear® Pro Armband underestimated energy expenditure by 25% during stage 3 and 27% during stage 4. Bland-Altman plots indicated the low agreement for measures of energy expenditure between the

SenseWear® Pro 2 Armband and the respiratory metabolic system during graded treadmill walking/jogging. The magnitude of this difference increased as energy expenditure increased.

The observation that the measures of energy expenditure were significantly different between the SenseWear® Pro 2 Armband and the respiratory metabolic system when treadmill grade increased, is consistent with the three previous adult studies. Jakicic et al. examined the accuracy of the SenseWear® Pro Armband in estimating energy expenditure in adults (females and males) during treadmill walking/jogging [71]. The armband significantly underestimated energy expenditure during treadmill walking on a 5% (0.3 + 0.6 $kcal \cdot min^{-1}$, p< 0.016) and 10% grade (2.4 + 0.9 $kcal \cdot min^{-1}$, p<0.016) when compared to respiratory metabolic measures. Fruin et al. used the SenseWear® Pro Armband to measure energy expenditure in 20 adult (10 male and 10 female) subjects during inclined treadmill walking [72]. Results indicated that the SenseWear® Pro Armband estimate of energy expenditure increased with increasing treadmill speed but not inclination. The SenseWear® Pro Armband significantly underestimated (22%, p<0,001) energy expenditure required to walk at a 5% treadmill grade.

5.3.2.1. Mechanisms for the Underestimation of Energy Expenditure during Graded Treadmill Walking/Jogging

When the present findings are examined in conjunction with previous reports, it appears that the SenseWear® Pro 2 Armband underestimates energy expenditure for both adolescents and adults performing graded treadmill walking/jogging. There are several mechanisms that may explain the lower energy expenditure estimates derived from the SenseWear® Pro 2 Armband.

Accelerometer Input: While it cannot be directly determined, it is possible that during treadmill exercise the primary signal to the energy expenditure model of the SenseWear® Pro 2 Armband is derived from the two-axis accelerometer. Historically, accelerometers have had difficulty accurately measuring energy expenditure during incline walking/running [6, 85]. Uniaxial accelerometers, the WAM and Caltrac, were able to discriminate between changes in speed, but not to changes in grade during treadmill walking and running [3, 7]. Nichols et al. reported the Tritrac (a commercially available triaxial accelerometer) underestimated energy expenditure by 13 percent when treadmill grade was increased from 0% to 5% [74]. It was concluded that the Tritrac could accurately distinguish various intensities of walking/jogging on level ground, but it is insensitive to changes in grade. Levine et al. reported that the Tracmor, a triaxial accelerometer system, failed to detect the increased energetic cost of walking on a positive incline [6]. The elevated energy expenditure that occurs when walking up an incline was not detected by triaxial accelerometers. Energy expenditure underestimations using accelerometry ranged from 8-21% in the previous investigations and were attributed to the inability of the device to detect the change in exercise intensity that occurs with an increase in incline [74, 85, 86]. The error in predicting the energy expenditure during walking and jogging on an incline is due to the inability of the accelerometer to detect the external work performed in carrying one's body weight up an incline [87].

In a study comparing three accelerometry-based physical activity monitors (one triaxial and two uniaxial accelerometers), Welk et al. reported strong and consistent correlations (r=0.85-0.92) among the three different monitors in and VO2. As a result of this study and others [41, 43], it was concluded that the various accelerometry based devices provide similar information despite different technologies [41]. Similar to the uniaxial and triaxial accelerometers, it might follow that the two-axis accelerometer in the SenseWear® Pro 2 Armband was not capable of detecting the increase in exercise intensity that accompanies walking/jogging on an incline. This inability to accurately measure exercise intensity and thus the metabolic cost of the activity, could lead to underestimation of energy expenditure. Haskell et al concluded, “while the accelerometer quite accurately tracks change in the speed, it does not respond in any quantitative way to changes in slope [66]. This in part may explain the underestimation of energy expenditure by the SenseWear® Pro 2 Armband during walking/jogging on an incline in this investigation.

In a study by Jakicic et al., it was concluded the vertical force vector is the significant contributor to walking movement recorded by accelerometers. However, Jakicic noted that there is also motion occurring in the horizontal (moving forward) and lateral (side to side motion of the hips) planes, and the contribution of these force vectors may change as one moves from level to graded walking [85]. The SenseWear® Pro 2 Armband’s two-axis accelerometer is limited to detection of movement in two planes. Thus, it may be ineffective in detecting the various movements (lateral and anteroposterior) associated with graded treadmill walking/jogging.

At faster speeds, walking becomes less economical and the relation as evidenced by a disproportionate increase in energy cost related to walking speed [77]. As such, for a given distance traveled, greater total caloric expenditure occurs at faster walking speeds, making them less efficient. Here again, measuring body movement in two planes during exercise that is less efficient may result in underestimation of energy expenditure.

Body Heat Sensor Input: Given the apparent limitations of the accelerometer component of the SenseWear® Pro 2 Armband to accurately measure the energy expenditure of incline walking/jogging, it would be logical that the armband rely more on input from the body heat sensors. When exercise intensity increases, as is the case in graded treadmill walking/jogging, more body heat is generated [77]. However, the delay in response between the onset of heat production in muscle during exercise and when the monitor detects the change in body temperature on the skin surface may blunt the signal from the body temperature sensors. Combined with the short length of time for each exercise stage (four minutes), it is probable that the heat recorded by the body temperature sensors in the armband was not accurately reflective of the muscle heat production with higher intensity exercise. The delay in body heat transfer and the comparatively short exercise stages employed in this investigation may have contributed to the underestimation of energy expenditure by the SenseWear® Pro 2 Armband.

5.4. TOTAL ENERGY EXPENDITURE

5.4.1. Cycle Ergometer

The SenseWear® Pro 2 Armband significantly underestimated total energy expenditure compared to the respiratory metabolic system during the cycle ergometer protocol (i.e. warm up, stage 1, stage 2, cool down) in adolescent females and males and the combined female and male sample. The SenseWear® Pro 2 Armband significantly underestimated total energy expenditure by 52% for females, 43% for males and 47% for the combined group. Intraclass correlations relating total energy expenditure from the two devices for the cycle ergometer exercise were low (0.138-0.163) for females, males, and females and males combined. These low correlations are consistent with the poor agreement between measuring devices for total energy expenditure as indicated in the Bland-Altman plots of cycle ergometer data for adolescent females, males, and the combined sample. These plots indicated that the prediction error was highest in individuals who expended 30 total kcals during the cycle ergometer trial.

The findings in this investigation are consistent with a study by Jakicic et al. where the SenseWear® Pro 2 Armband underestimated total energy expenditure by 29% during a 20 minute cycle ergometer protocol in an adult female and male sample [71]. Bland-Altman plots demonstrated that the difference between total energy expenditure measured by the SenseWear® Pro 2 Armband and the respiratory metabolic system during cycle ergometer exercise were greatest at the highest energy expenditure levels. The mechanisms that likely accounted for the underestimation of total energy expenditure as measured by the SenseWear® Pro 2 Armband during cycle ergometer exercise have been thoroughly discussed in a previous section titled, *Mechanisms for the Energy Expenditure Underestimation during Cycle Ergometer Exercise (pages 78-82).* As such, these mechanisms will not be examined further.

5.4.2. Treadmill

The SenseWear® Pro 2 Armband significantly underestimated total energy expenditure during the treadmill protocol (i.e. warm up, stage 1, stage 2, stage 3, stage 4, cool down) compared to the respiratory metabolic system in both female and male adolescent subjects. Significant differences in total energy expenditure were also found between devices in the combined female and male sample. The SenseWear® Pro 2 Armband significantly underestimated total energy expenditure by 32% for females, 11% for males and 17% for the combined group. The intraclass correlations of total energy expenditure between the two devices during treadmill exercise were poor to average (0.137-0.622) for females, males, and females and males combined. The Bland-Altman plots indicated low (females and the combined sample) to modest (males) agreement between devices. The difference between devices (i.e. estimation error) was greatest at the higher energy expenditure level.

The findings in this investigation are consistent with a study by Jakicic et al. where the SenseWear® Pro 2 Armband significantly underestimated total energy expenditure by 7% during a 30 minute treadmill protocol in an adult female and male sample [71]. Similar to this investigation, the Bland-Altman plots displayed a greater magnitude of difference for total energy expenditure between the two devices as energy expenditure increased. The mechanisms that accounted for the underestimation of total energy expenditure as measured by the SenseWear® Pro 2 Armband during treadmill exercise have been thoroughly discussed in a previous sections titled *Mechanisms for the Energy Expenditure Underestimation during Level Treadmill Walking (pages 85-88)* and *Mechanisms for the Energy Expenditure Underestimation during Graded Treadmill Walking (pages 89-92).* As such, these mechanisms will not be examined further.

5.5. RESTING ENERGY EXPENDITURE

The validity of SenseWear® Pro 2 Armband to estimate resting energy expenditure varied somewhat depending on whether the measures were taken prior to the cycle or treadmill trials. In female subjects, measures of resting energy expenditure were significant lower from the SenseWear® Pro 2 Armband than from the respiratory metabolic system prior to the cycle ergometer. Prior to the treadmill exercise trial measures of resting energy expenditure were not significantly different between devices for adolescent female subjects. On average, the two resting energy expenditure trials differed by 17% (prior to the cycle ergometer) and by 7% (prior to the treadmill).

In male subjects, there were no significant differences in measures of resting energy expenditure between devices prior to both the cycle ergometer and treadmill exercise trials. On average, the two resting energy expenditure trials differed by 7% (prior to the cycle ergometer) and by 7% (prior to the treadmill).

When males and females were combined, there were no significant differences in measures of resting energy expenditure between devices prior to both the cycle ergometer and treadmill exercise trials. On average, the two resting energy expenditure trials differed by 8% (prior to the cycle ergometer) and by 7% (prior to the treadmill).

Only one of the previously published adult studies used the SenseWear® Pro 2 Armband to measure resting energy expenditure compared to indirect calorimetry. Fruin et al. concluded that the SenseWear® Pro 2 Armband's measures of resting energy expenditure were valid when compared to indirect calorimetry based upon the observation that there were no significant differences between devices [72].

The SenseWear® Pro 2 Armband's algorithm's to predict energy expenditure are proprietary, but the formulas use both sensor data and personal characteristics of the individual (weight, height, age, gender). It is unknown how the physiological data from the sensors factor into the estimation of resting energy expenditure.

In general, the SenseWear® Pro 2 Armband's estimates of resting energy expenditure were valid when compared to measures from the respiratory metabolic system. In three of the four resting energy expenditure trials (2 female, 2 male), there were no significant differences between measuring devices. The difference in resting energy expenditure observed for females prior to cycle ergometer cannot readily be explained. A one-way ANOVA was calculated to determine if there was an effect of testing order that might influence these results. No order effect was detected.

5.6. APPLICATION ISSUES

This was the first validation study conducted using the SenseWear® Pro 2 Armband to estimated energy expenditure during cycling, walking, and jogging in adolescent female and male subjects. The results of this study indicate that for cycle ergometer exercise, the SenseWear® Pro 2 Armband significantly underestimates energy expenditure for both adolescent males and females. This raises questions regarding the use of the armband with its reliance on the two-axis accelerometer to accurately predict energy expenditure during cycling, a non-weight bearing exercise.

For level treadmill walking, the SenseWear® Pro 2 Armband proved to be accurate in estimating energy expenditure in adolescent males. For females, however significant differences in level treadmill walking were found which might be associated with differences in walking movement and body composition specific to adolescent females.

During graded treadmill walking/jogging, the SenseWear® Pro 2 Armband systematically underestimated energy expenditure in adolescent females and males. If there is primary reliance on the two-axis accelerometer to estimate the increased energy expenditure associated with walking/jogging on an incline, then this technology may lead to lower energy expenditure values. These findings impose limitations on the use of the SenseWear® Pro 2 Armband during locomotor activities involving an inclined surface.

In general, the SenseWear® Pro 2 Armband was valid in estimating resting energy expenditure in adolescent males and females. It appears that the SenseWear® Pro 2 Armband's use is limited to estimating resting energy expenditure in adolescents and to estimating physical activity energy expenditure in males during level walking. Further research and refinement on the SenseWear® Pro 2 Armband's algorithms are needed before the device can be used to estimate energy expenditure in other modes of exercise and during a free-living setting. A valid physical activity monitor, such as SenseWear® Pro 2 Armband, that is able to accurately measure physical activity energy expenditure could be used to answer long standing questions about physical activity patterns, energy imbalance, compliance with physical activity guidelines and the dose-response relation between activity and health.

5.7. CONCLUSION

The result of this investigation indicate that the SenseWear® Pro 2 Armband was not a valid instrument to measure energy expenditure of healthy adolescent females and males during most of the cycling and walking/jogging exercise conditions that were examined. The SenseWear® Pro 2 Armband significantly underestimated energy expenditure during cycle ergometer and graded treadmill walking in both adolescent female and male subjects. For level treadmill walking, the SenseWear® Pro 2 Armband was accurate in estimating energy expenditure in adolescent males, but not females. However, when the error in energy expenditure estimations from the SenseWear® Pro 2 Armband are compared to error estimations of triaxial accelerometers, in general the error is reduced. Triaxial accelerometer estimates of energy expenditure during level walking typically overestimate by 12-49%, during walking up an incline they underestimate by 8-21% and during cycling they underestimate by 53-68% compared to indirect calorimetry [72, 74, 85]. Error estimations from the SenseWear® Pro 2 Armband in this study ranged during level treadmill walking from 6-21%, during walking/jogging on an incline from 19-34%, and during cycling from 46-53% when compared to the respiratory metabolic system.

This was the first study to examine the accuracy of the SenseWear® Pro 2 Armband to measure energy expenditure in adolescent females and males during various physical activities.

The present findings suggest that the possible mechanisms underlying the underestimation of energy expenditure are complex but may include: the use of generalized exercise algorithms to predict all types of physical activity; the disproportionate reliance on the two-axis accelerometer during non-weight bearing and graded exercises; the delay in detecting body heat transfer to the skin; and the inability to account for variability in walking gait, lean body mass and fat mass. All of these factors impact the accuracy of the SenseWear® Pro 2 Armband to accurately measure energy expenditure. These findings are an important first step in validating SenseWear® Pro 2 Armband technology in adolescents.

5.8. LIMITATIONS

- In the present investigation there were several methodological limitations that need to be considered.
    - Only cycling, walking and jogging exercise modes were tested. Future studies could examine these as well as many other modes of physical activity typical of adolescents.
    - The exercise stages were four minutes in duration. Since the body heat transfer is delayed and the SenseWear® Pro 2 Armband heat sensors work better in protocols lasting longer than eight minutes, various exercise durations could be examined.
    - At the recommendation of the manufacturer, BodyMedia, the SenseWear® Pro 2 Armband was placed on the upper right arm of the subject 30 minutes prior to the start of the study protocol to allow the armband to adjust to body temperature. In most cases, the 30-minute adjustment period was followed. However, due to unforeseen methodological circumstances, the armband adjustment time was longer in a few subjects but never exceeded 35 minutes. It could not be

determined if this variability in the temperature adjustment period influenced the measures of resting energy expenditure, creating measurement bias. In future studies, a standardized adjustment period should be implemented in the protocol.

- The fourth minute of each exercise stage was used as the $kcal \cdot min^{-1}$ value in statistical analysis to represent energy expenditure from the entire exercise stage. This fourth minute value was used, as it was expected that a steady physiological response, if present would have occurred at this time point. However, this fourth minute $kcal \cdot min^{-1}$ response may not have been the most representative response for all subjects. Other calculations that could be used are averaging the third and fourth minute responses.

5.9. RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the findings of this investigation, future research on the validation of the SenseWear® Pro 2 Armband to measure energy expenditure could consider the following:

- The present investigation used the most current available algorithms (generalized algorithms) for the SenseWear® Pro 2 Armband. Activity-specific algorithms, as they become available for use in adolescents, could be evaluated to determine if there is an improvement in accuracy of energy expenditure estimates.
- The SenseWear® Pro 2 Armband algorithms for estimating resting and physical activity energy expenditures were developed for adult subjects and prior to this investigation, have been exclusively tested in adult subjects. Algorithms based on adolescent energy expenditure data, may provide more accurate energy expenditure estimations.

- This investigation was conducted on healthy normal weight adolescents. It is unclear whether similar results would be found in children/adolescents of different ages, body weights and body composition.
- The SenseWear® Pro 2 Armband was developed to measure energy expenditure in the free-living environment. It would be interesting to compare total energy expenditure from the armband to energy expenditure derived using doubly labeled water as the criterion measure of energy expenditure in free living.

APPENDIX A

BODY MASS INDEX FOR BOYS

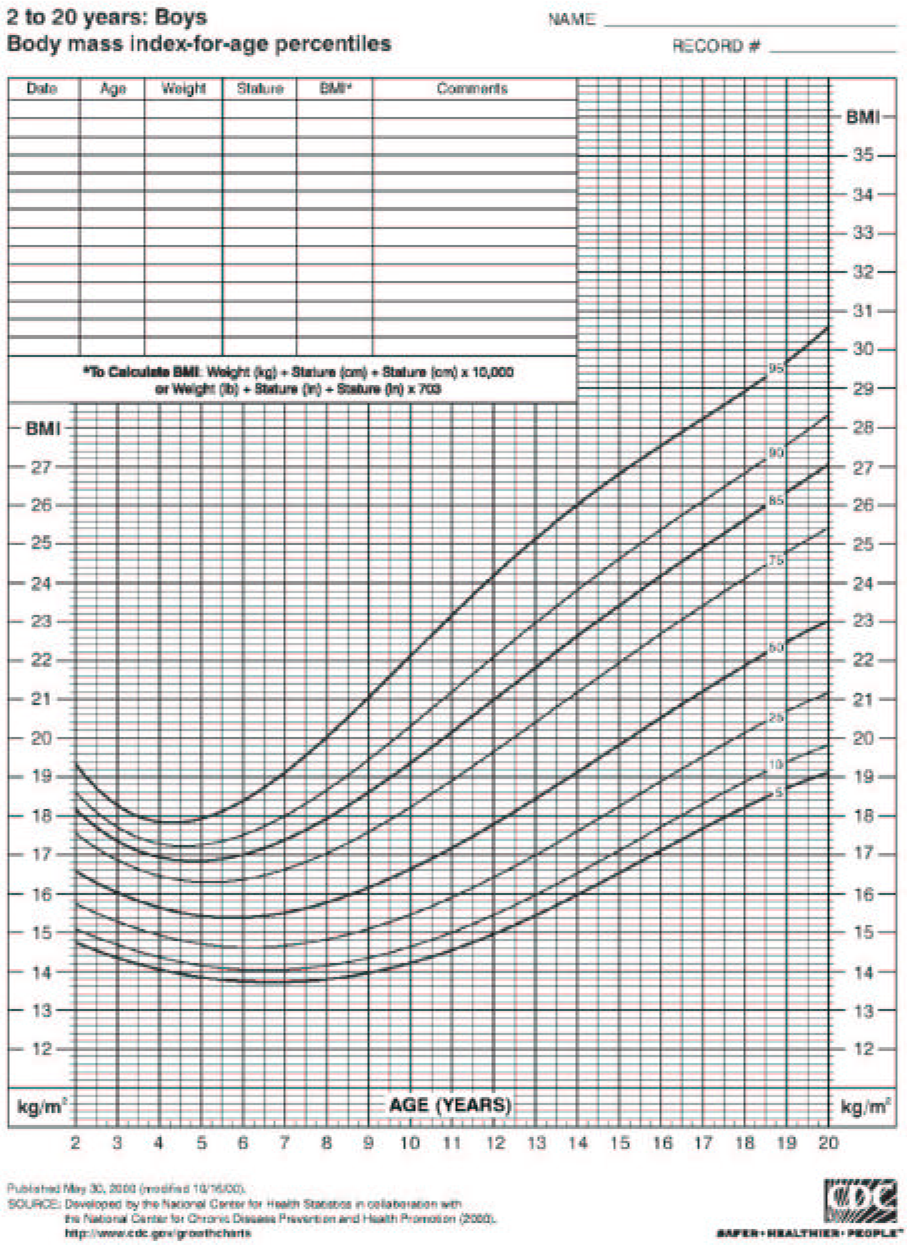


Figure 26: Body Mass Index for Boys

APPENDIX A

BODY MASS INDEX FOR GIRLS

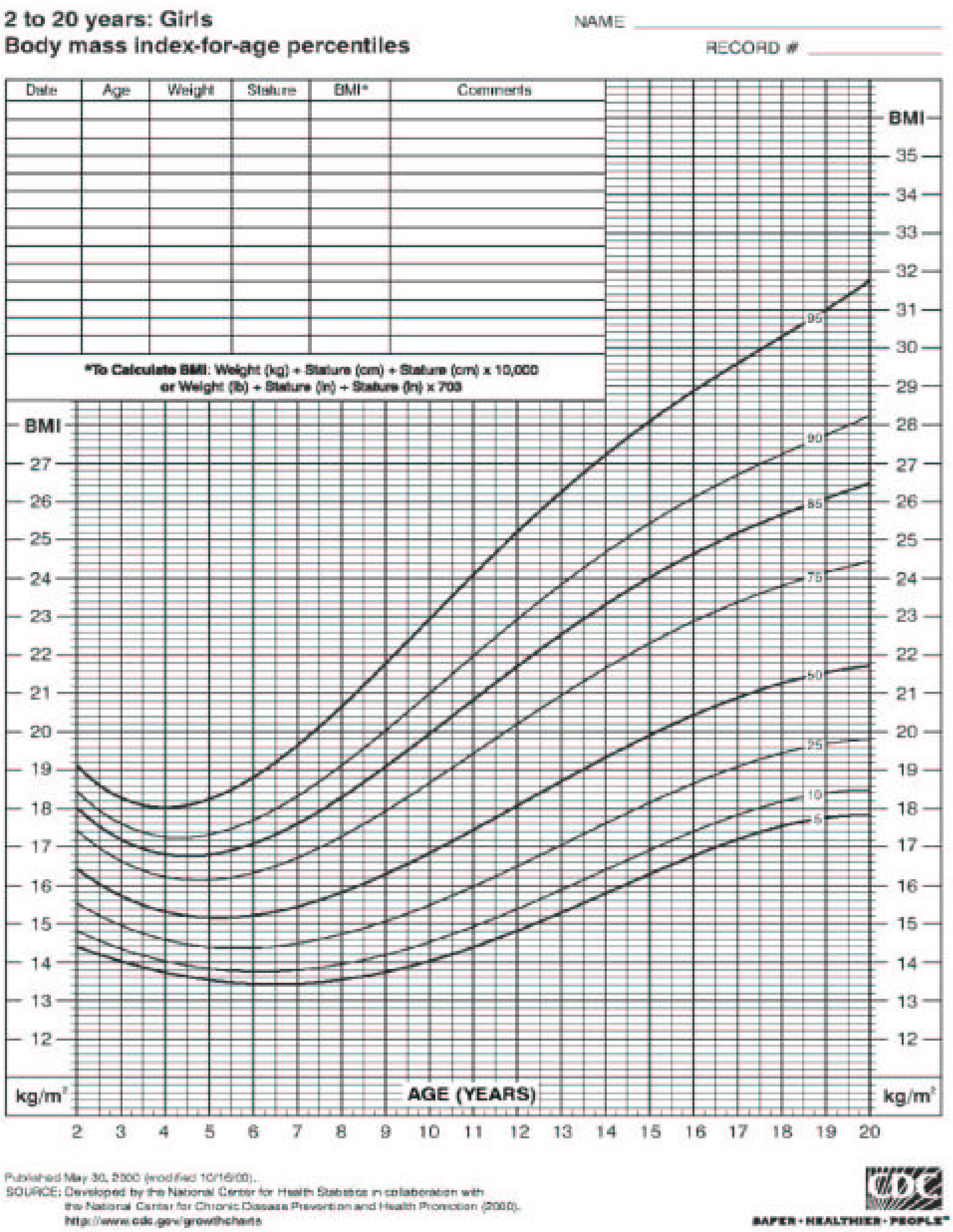


Figure 27: Body Mass Index Chart for Girls

APPENDIX B

PREPARTICIPATION MEDICAL SCREENING & PHSICAL ACTIVITY HISTORY

Name:______________________________________ Age:_______ Gender:________
Parent/Guardian:____
Address:____
Physician:_______________________________________ Telephone:_____________
Medical Insurance Carrier:__________________________ Telephone:_____________
Person to notify in case of an emergency (parent/grandparent/guardian):
Name:_________________________ Relationship:___________ Telephone:___________
Allergies:____
Current Medication(s):____
Height:_________________ Weight:_________________ Body Mass Index:______

Please indicate if your child has or has ever had any of the following medical conditions:

Disease/Condition	No	Yes	Dates	Disease/Condition	No	Yes	Date(s)
Congenital heart disease				Diabetes mellitus			
Cardiomyopathy				High blood pressure			
Heart murmur				High blood cholesterol			
Asthma				Liver disease			
Chronic cough				Rheumatic fever			
Epilepsy				Kidney disease			
Anemia				Cancer			
Anorexia nervosa				Bleeding disorder			
Bulimia nervosa				Osteoarthritis			
Current Pregnancy							

If Yes to any of the above, please explain:____
____
____

Symptoms

Please indicate if your child has or has ever had any of the following symptoms during exercise:

Symptom	**No**	**Yes**	**Dates**	**Symptom**	**No**	**Yes**	**Date(s)**
Dizziness, fainting				Excessive muscle soreness			
Blackouts				Excessive bruising			
Persistent chest pain				Heat exhaustion			
Chest tightness				Heat stroke			
Wheezing				Shortness of breath			

If Yes to any of the above, please explain:____

A "Yes" response to any of the statements on page 1 indicates a potential increased risk of injury to your child during exercise. For that reason, he/she will not be able to participate in the current research study.

Orthopedic History

Please indicate if your child has or has ever had any of the following orthopedic problems:

Condition	No	Yes	Dates	Condition	No	Yes	Date(s)
Bone fracture				Skull fracture			
Hospitalized for a head injury				Ruptured disk			
Orthopedic surgery				Sprain			

Health & Physical Activity History

Answer the following questions by circling either "yes" or "no to the following questions.

1. Do you or does your son/daughter smoke cigarettes?	No	Yes
2. Are you or is your son/daughter physically active for 30 minutes or more on most, if not all, days of the week?	No	Yes
3. Do you or does your child participate in sports?	No	Yes

Answer the following questions by indicating the amount of time (in minutes) spent in the specified activity.

	Time (minutes)
1. How many hours per week, on average, do you or does your child spend in leisure time physical activity?	
2. How many hours per week, on average, do you or does your child spend participating in sports?	
3. How many hours per week, on average, do you or does your child spend in sedentary activities?	

I declare the above information to be accurate and a true reflection of ____ (participant's name) physical condition.

Participant's Signature:______________________________ Date:_______
Parent (s)/Guardian Signature:__________________________ Date:_______
__________________________ Date:_______

APPENDIX C

ONE-WAY ANOVA ORDER EFFECT

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
ExerCeAB	Cycle first	12	20.9050	5.99623	1.73096	17.0952	24.7148
	TM first	11	20.4736	7.51294	2.26524	15.4264	25.5209
	Total	23	20.6987	6.60927	1.37813	17.8406	23.5568
ExerCeRM	Cycle first	12	39.2658	4.45119	1.28495	36.4377	42.0940
	TM first	11	40.4127	4.71003	1.42013	37.2485	43.5770
	Total	23	39.8143	4.50926	.94025	37.8644	41.7643
ExerTmAb	Cycle first	12	100.3783	13.80301	3.98459	91.6083	109.1484
	TM first	11	105.0600	12.47936	3.76267	96.6763	113.4437
	Total	23	102.6174	13.10602	2.73279	96.9499	108.2849
ExerTmRm	Cycle first	12	123.2808	19.53956	5.64059	110.8660	135.6957
	TM first	11	129.6164	23.73017	7.15491	113.6742	145.5585
	Total	23	126.3109	21.38533	4.45915	117.0632	135.5586

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
ExerCeAB	Between Groups	1.068	1	1.068	.023	.880
	Within Groups	959.945	21	45.712		
	Total	961.013	22			
ExerCeRM	Between Groups	7.549	1	7.549	.360	.555
	Within Groups	439.787	21	20.942		
	Total	447.336	22			
ExerTmAb	Between Groups	125.790	1	125.790	.723	.405
	Within Groups	3653.100	21	173.957		
	Total	3778.890	22			
ExerTmRm	Between Groups	230.363	1	230.363	.492	.491
	Within Groups	9830.949	21	468.140		
	Total	10061.312	22			

Table 5: One-Way ANOVA Order Effect Exercise Protocol

APPENDIX C (continued)

ONE-WAY ANOVA ORDER EFFECT

Descriptives

		Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
RestCeAB	Cycle first	6.0550	1.05860	.30559	5.3824	6.7276
	TM first	6.7055	1.88173	.56736	5.4413	7.9696
	Total	6.3661	1.51003	.31486	5.7131	7.0191
RestCeRM	Cycle first	6.9050	.80305	.23182	6.3948	7.4152
	TM first	7.3709	1.37557	.41475	6.4468	8.2950
	Total	7.1278	1.11317	.23211	6.6465	7.6092
RestTMAB	Cycle first	6.1850	.99509	.28726	5.5527	6.8173
	TM first	6.5345	1.76290	.53153	5.3502	7.7189
	Total	6.3522	1.39270	.29040	5.7499	6.9544
RestTMRM	Cycle first	6.7342	.75769	.21873	6.2528	7.2156
	TM first	7.1173	1.18690	.35786	6.3199	7.9146
	Total	6.9174	.98268	.20490	6.4924	7.3423

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RestCeAB	Between Groups	2.428	1	2.428	1.068	.313
	Within Groups	47.736	21	2.273		
	Total	50.164	22			
RestCeRM	Between Groups	1.246	1	1.246	1.006	.327
	Within Groups	26.016	21	1.239		
	Total	27.261	22			
RestTMAB	Between Groups	.701	1	.701	.351	.560
	Within Groups	41.970	21	1.999		
	Total	42.672	22			
RestTMRM	Between Groups	.842	1	.842	.867	.362
	Within Groups	20.402	21	.972		
	Total	21.245	22			

Table 6: One-Way ANOVA Order Effect Resting Period

APPENDIX D

TWO-WAY ANOVA ENERGY EXPENDITURE DURING CYCLE ERGOMETER EXERCISE IN FEMALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1ABmin	1.5258	.48461	12
St1RMmin	3.1142	.38625	12
St2ABmin	1.9242	1.09655	12
St2RMmin	4.5167	.53510	12

Tests of Within-Subjects Effects
Measure: MEASURE_1

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	9.729	1	34.226	.000	.757	1.000
	Greenhouse-Geisser	9.729	1.000	34.226	.000	.757	1.000
	Huynh-Feldt	9.729	1.000	34.226	.000	.757	1.000
	Lower-bound	9.729	1.000	34.226	.000	.757	1.000
Error(time)	Sphericity Assumed	3.127	11				
	Greenhouse-Geisser	3.127	11.000				
	Huynh-Feldt	3.127	11.000				
	Lower-bound	3.127	11.000				
device	Sphericity Assumed	52.438	1	105.015	.000	.905	1.000
	Greenhouse-Geisser	52.438	1.000	105.015	.000	.905	1.000
	Huynh-Feldt	52.438	1.000	105.015	.000	.905	1.000
	Lower-bound	52.438	1.000	105.015	.000	.905	1.000
Error(device)	Sphericity Assumed	5.493	11				
	Greenhouse-Geisser	5.493	11.000				
	Huynh-Feldt	5.493	11.000				
	Lower-bound	5.493	11.000				
time * device	Sphericity Assumed	3.025	1	24.024	.000	.686	.993
	Greenhouse-Geisser	3.025	1.000	24.024	.000	.686	.993
	Huynh-Feldt	3.025	1.000	24.024	.000	.686	.993
	Lower-bound	3.025	1.000	24.024	.000	.686	.993
Error(time*device)	Sphericity Assumed	1.385	11				
	Greenhouse-Geisser	1.385	11.000				
	Huynh-Feldt	1.385	11.000				
	Lower-bound	1.385	11.000				

a Computed using alpha = .05

Table 7: ANOVA Energy Expenditure during Cycle Ergometer in Female Subjects

APPENDIX E

POST HOC COMPARISON FOR CYCLE ERGOMETER RESPONSES IN FEMALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1ABmin	1.5258	12	.48461	.13989
	St1RMmin	3.1142	12	.38625	.11150
Pair 2	St2ABmin	1.9242	12	1.09655	.31655
	St2RMmin	4.5167	12	.53510	.15447

Paired Samples Test

		Paired Differences					
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)
					Lower	Upper	
Pair 1	St1ABmin - St1RMmin	-1.58833	.60047	.17334	-1.96985	-1.20681	.000
Pair 2	St2ABmin - St2RMmin	-2.59250	.94337	.27233	-3.19189	-1.99311	.000

Table 8: Post hoc Comparison for Cycle Ergometer Responses in Female Subjects

APPENDIX F

BLAND-ATLMAN PLOTS FOR CYCLE ERGOMETER RESPONSES FOR FEMALE SUBJECTS

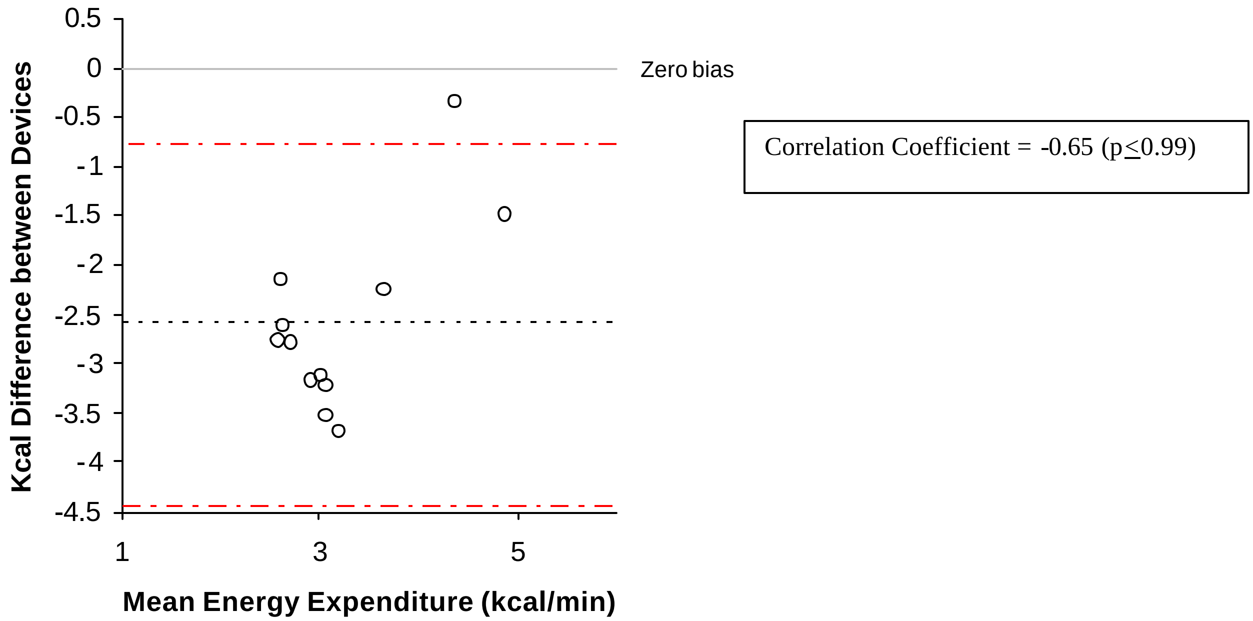


Figure 28: Bland-Altman Plot Stage 2 Cycle Ergometer Responses for Female Subjects

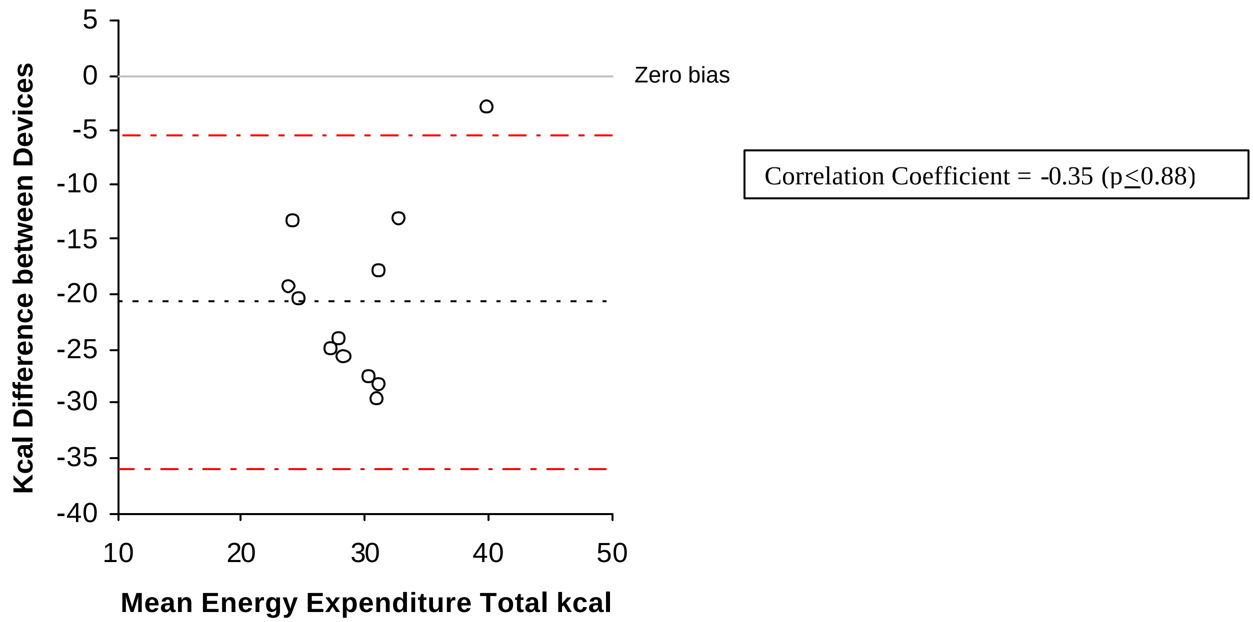


Figure 29: Bland-Altman Plot Total Energy Expenditure Cycle Ergometer Responses for Female Subjects

APPENDIX G

INTRACLASS CORRELATION FOR CYCLE ERGOMETER ENERGY EXPENDITURE IN FEMALE SUBJECTS

Stage 1: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.008(b)	-.044	.154	1.130	11.0	11	.421
Average Measures	.016(c)	-.094	.271	1.130	11.0	11	.421

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Stage 2: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.074(b)	-.048	.356	2.346	11.0	11	.087
Average Measures	.137(c)	-.121	.560	2.346	11.0	11	.087

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 9: Intraclass correlations for Cycle Ergometer Exercise in Female Subjects

APPENDIX H

TWO-WAY ANOVA ENERGY EXPENDITURE DURING CYCLE ERGOMETER EXERCISE IN MALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1ABmin	1.6855	.65811	11
St1RMmin	3.1473	.45848	11
St2ABmin	2.1355	1.04081	11
StRMmin	4.5036	.54897	11

Tests of Within-Subjects Effects
Measure: MEASURE_1

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	8.973	1	12.780	.005	.561	.895
	Greenhouse-Geisser	8.973	1.000	12.780	.005	.561	.895
	Huynh-Feldt	8.973	1.000	12.780	.005	.561	.895
	Lower-bound	8.973	1.000	12.780	.005	.561	.895
Error(time)	Sphericity Assumed	7.021	10				
	Greenhouse-Geisser	7.021	10.000				
	Huynh-Feldt	7.021	10.000				
	Lower-bound	7.021	10.000				
Device	Sphericity Assumed	40.339	1	90.871	.000	.901	1.000
	Greenhouse-Geisser	40.339	1.000	90.871	.000	.901	1.000
	Huynh-Feldt	40.339	1.000	90.871	.000	.901	1.000
	Lower-bound	40.339	1.000	90.871	.000	.901	1.000
Error(device)	Sphericity Assumed	4.439	10				
	Greenhouse-Geisser	4.439	10.000				
	Huynh-Feldt	4.439	10.000				
	Lower-bound	4.439	10.000				
time * device	Sphericity Assumed	2.259	1	9.559	.011	.489	.795
	Greenhouse-Geisser	2.259	1.000	9.559	.011	.489	.795
	Huynh-Feldt	2.259	1.000	9.559	.011	.489	.795
	Lower-bound	2.259	1.000	9.559	.011	.489	.795
Error(time*device)	Sphericity Assumed	2.363	10				
	Greenhouse-Geisser	2.363	10.000				
	Huynh-Feldt	2.363	10.000				
	Lower-bound	2.363	10.000				

a Computed using alpha = .05

Table 10: Two-Way ANOVA Energy Expenditure during Cycle Ergometer Exercise in Male Subjects

APPENDIX I

POST HOC COMPARISON FOR CYCLE ERGOMETER RESPONSES IN MALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1ABmin	1.6855	11	.65811	.19843
	St1RMmin	3.1473	11	.45848	.13824
Pair 2	St2ABmin	2.1355	11	1.04081	.31382
	StRMmin	4.5036	11	.54897	.16552

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-1.46182	.62042	.18706	-1.87862	-1.04502	-7.815	10	.000
-2.36818	.98772	.29781	-3.03174	-1.70462	-7.952	10	.000

Table 11: *Post hoc* Comparison for Cycle Ergometer Responses in Male Subjects

APPENDIX J

BLAND-ALTMAN PLOT CYCLE ERGOMETER RESPONSES FOR MALE SUBJECTS

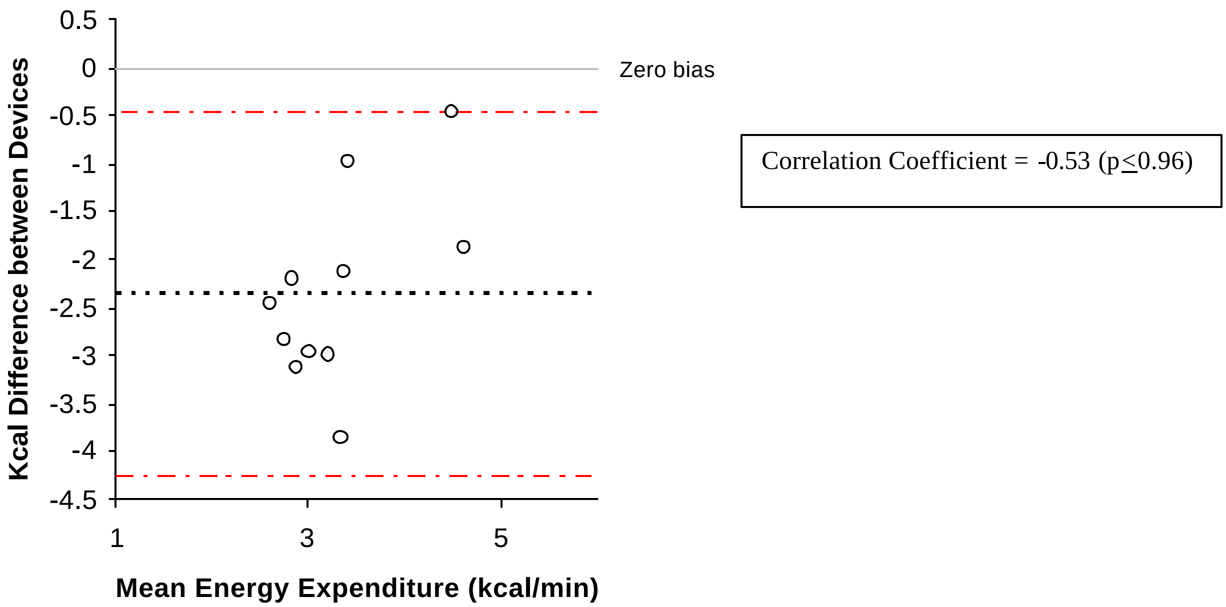


Figure 30: Bland-Altman Plot Stage 2 Cycle Ergometer for Male Subjects

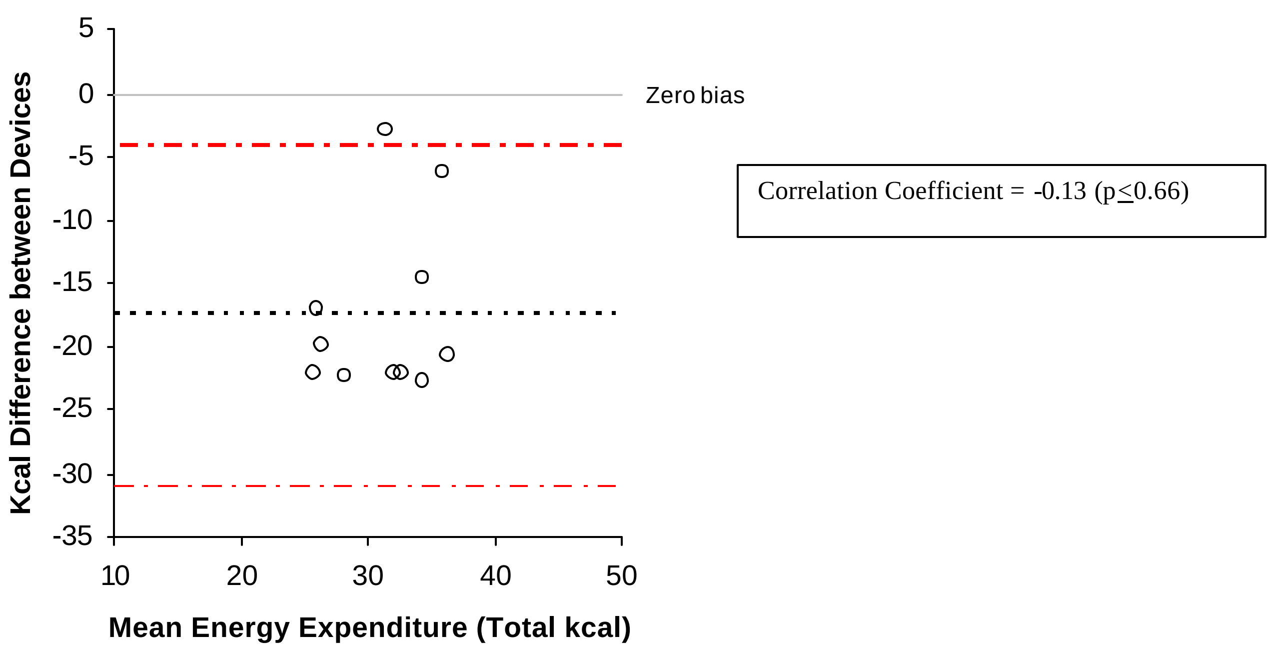


Figure 31: Bland-Altman Plot Total Energy Expenditure Cycle Ergometer for Male Subjects

APPENDIX K

INTRACLASS CORRELATION FOR CYCLE ERGOMETER ENERGY EXPENDITURE IN MALE SUBJECTS

Stage 1: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.094(b)	-.063	.428	2.343	10.0	10	.098
Average Measures	.172(c)	-.161	.629	2.343	10.0	10	.098

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwis e.

Stage 2: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.059(b)	-.056	.335	1.839	10.0	10	.176
Average Measures	.112(c)	-.148	.537	1.839	10.0	10	.176

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the inte raction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 12: Intraclass correlation for Cycle Ergometer Exercise in Male Subjects

APPENDIX L

TWO-WAY ANOVA ENERGY EXPENDITURE DURING TREADMILL EXERCISE IN FEMALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1min1	3.9300	.33330	12
St1min2	4.5850	.75851	12
St2min1	4.9958	.30947	12
St2min2	6.3350	.73806	12
St3min1	5.5600	.43505	12
St3min2	8.4600	.77318	12
St4min1	7.2050	1.13051	12
St4min2	10.9133	1.10788	12

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	300.834	3	241.258	.000	.956	1.000
	Greenhouse-Geisser	300.834	1.568	241.258	.000	.956	1.000
	Huynh-Feldt	300.834	1.782	241.258	.000	.956	1.000
	Lower-bound	300.834	1.000	241.258	.000	.956	1.000
Error(time)	Sphericity Assumed	13.716	33				
	Greenhouse-Geisser	13.716	17.243				
	Huynh-Feldt	13.716	19.605				
	Lower-bound	13.716	11.000				
device	Sphericity Assumed	111.005	1	194.195	.000	.946	1.000
	Greenhouse-Geisser	111.005	1.000	194.195	.000	.946	1.000
	Huynh-Feldt	111.005	1.000	194.195	.000	.946	1.000
	Lower-bound	111.005	1.000	194.195	.000	.946	1.000
Error(device)	Sphericity Assumed	6.288	11				
	Greenhouse-Geisser	6.288	11.000				
	Huynh-Feldt	6.288	11.000				
	Lower-bound	6.288	11.000				
time * device	Sphericity Assumed	35.300	3	59.833	.000	.845	1.000
	Greenhouse-Geisser	35.300	2.402	59.833	.000	.845	1.000
	Huynh-Feldt	35.300	3.000	59.833	.000	.845	1.000
	Lower-bound	35.300	1.000	59.833	.000	.845	1.000
Error(time*device)	Sphericity Assumed	6.490	33				
	Greenhouse-Geisser	6.490	26.426				
	Huynh-Feldt	6.490	33.000				

a Computed using alpha = .05

Table 13: Two-Way ANOVA Energy Expenditure during Treadmill Exercise in Female Subjects

APPENDIX M

POST HOC COMPARISON FOR TREADMILL RESPONSES IN FEMALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1min1	3.9300	12	.33330	.09622
	St1min2	4.5850	12	.75851	.21896
Pair 2	St2min1	4.9958	12	.30947	.08934
	St2min2	6.3350	12	.73806	.21306
Pair 3	St3min1	5.5600	12	.43505	.12559
	St3min2	8.4600	12	.77318	.22320
Pair 4	St4min1	7.2050	12	1.13051	.32635
	St4min2	10.9133	12	1.10788	.31982

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	St1min1 - St1min2	-.65500	.55325	.15971	-1.00652	-.30348	-4.101	11	.002
Pair 2	St2min1 - St2min2	-1.33917	.69624	.20099	-1.78154	-.89680	-6.663	11	.000
Pair 3	St3min1 - St3min2	-2.90000	.80913	.23358	-3.41410	-2.38590	-12.416	11	.000
Pair 4	St4min1 - St4min2	-3.70833	.93683	.27044	-4.30357	-3.11310	-13.712	11	.000

Table 14: *Post hoc* Comparison for Treadmill Responses in Female Subjects

APPENDIX N

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR FEMALE SUBJECTS

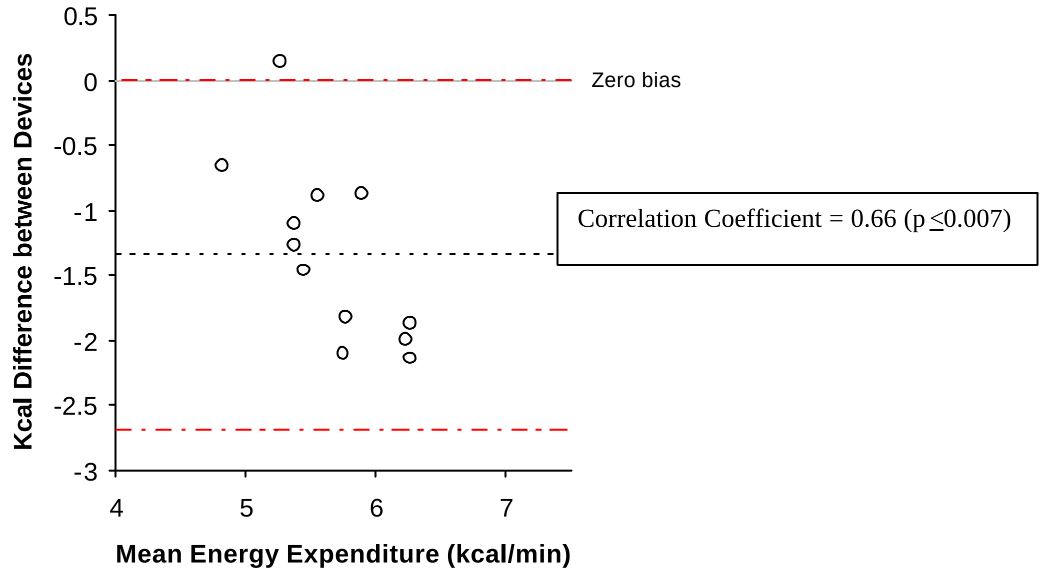


Figure 32: Bland-Altman Plot Treadmill Stage 2 for Female Subjects

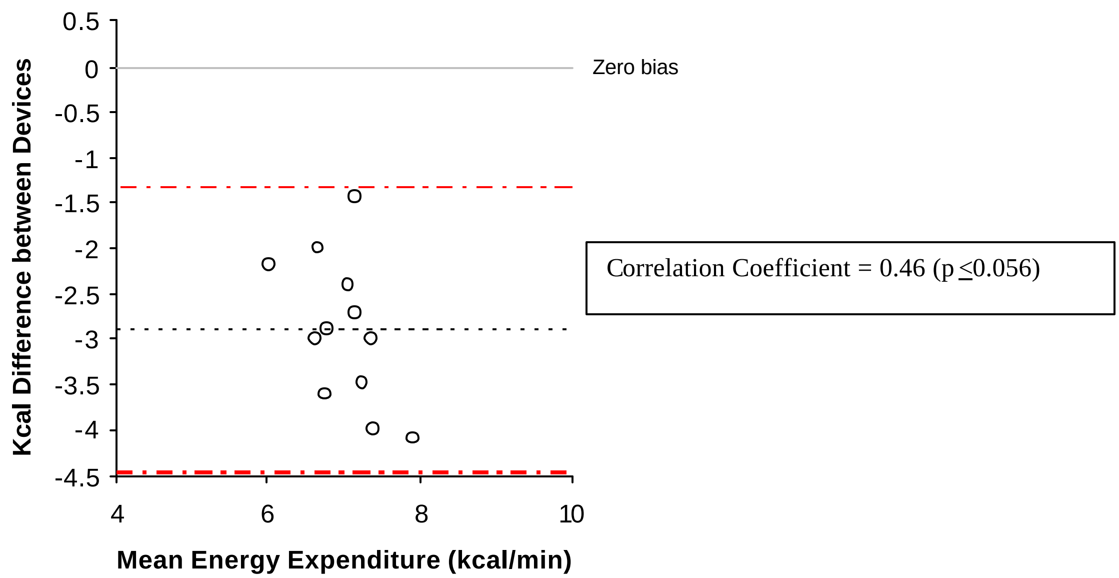


Figure 33: Bland-Altman Plot Treadmill Stage 3 for Female Subjects

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR FEMALE SUBJECTS

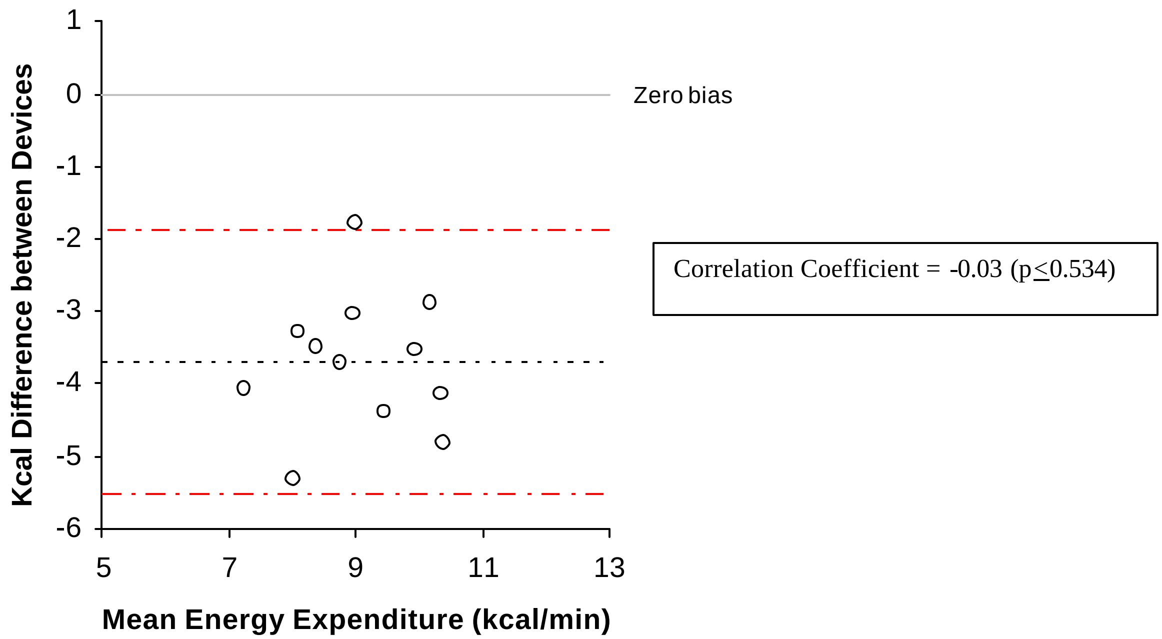


Figure 34 :Bland-Altman Plot Treadmill Stage 4 for Female Subjects

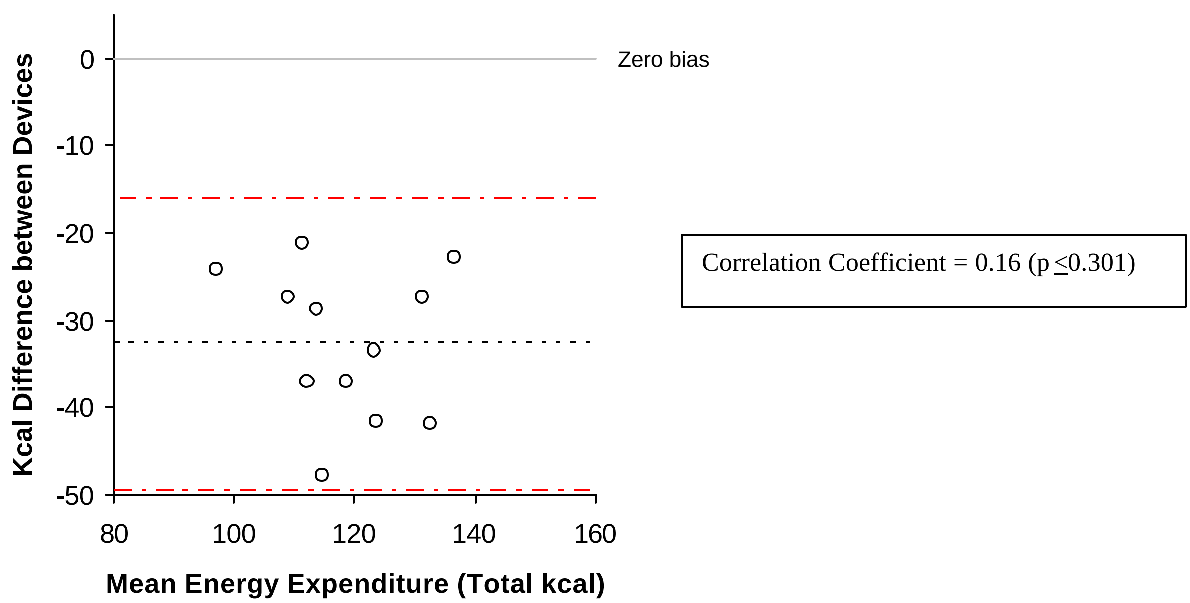


Figure 35: Bland-Altman Plot Treadmill Stage 3 for Female Subjects

APPENDIX O

INTRACLASS CORRELATION FOR TREADMILL ENERGY EXPENDITURE IN FEMALE SUBJECTS

Stage 1: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.349(b)	-.125	.742	3.485	11.0	11	.025
Average Measures	.517(c)	-.397	.860	3.485	11.0	11	.025

Stage 2: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.065(b)	-.075	.358	1.643	11.0	11	.212
Average Measures	.112(c)	-.207	.560	1.643	11.0	11	.212

Stage 3: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.014(b)	-.025	.130	1.404	11.0	11	.291
Average Measures	.029(c)	-.061	.255	1.404	11.0	11	.291

Stage 4: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.101(b)	-.028	.427	4.709	11.0	11	.008
Average Measures	.183(c)	-.062	.617	4.709	11.0	11	.008

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 15: Intraclass correlation for Treadmill Exercise in Female Subjects

APPENDIX P

TWO-WAY ANOVA ENERGY EXPENDITURE DURING TREADMILL EXERCISE IN MALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1min1	4.1108	.67833	12
St1min2	3.8933	.88703	12
St2min1	5.2325	.86910	12
St2min2	5.6242	1.18630	12
St3min1	5.6592	.92896	12
St3min2	7.0142	1.76580	12
St4min1	7.6975	1.58511	12
St4min2	9.9225	2.38629	12

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	293.872	3	133.038	.000	.924	1.000
	Greenhouse-Geisser	293.872	1.325	133.038	.000	.924	1.000
	Huynh-Feldt	293.872	1.437	133.038	.000	.924	1.000
	Lower-bound	293.872	1.000	133.038	.000	.924	1.000
Error(time)	Sphericity Assumed	24.298	33				
	Greenhouse-Geisser	24.298	14.575				
	Huynh-Feldt	24.298	15.803				
	Lower-bound	24.298	11.000				
device	Sphericity Assumed	21.141	1	10.390	.008	.486	.835
	Greenhouse-Geisser	21.141	1.000	10.390	.008	.486	.835
	Huynh-Feldt	21.141	1.000	10.390	.008	.486	.835
	Lower-bound	21.141	1.000	10.390	.008	.486	.835
Error(device)	Sphericity Assumed	22.381	11				
	Greenhouse-Geisser	22.381	11.000				
	Huynh-Feldt	22.381	11.000				
	Lower-bound	22.381	11.000				
time * device	Sphericity Assumed	20.784	3	20.519	.000	.651	1.000
	Greenhouse-Geisser	20.784	1.487	20.519	.000	.651	.998
	Huynh-Feldt	20.784	1.665	20.519	.000	.651	.999
	Lower-bound	20.784	1.000	20.519	.001	.651	.984
Error(time*device)	Sphericity Assumed	11.142	33				
	Greenhouse-Geisser	11.142	16.354				
	Huynh-Feldt	11.142	18.316				

a Computed using alpha = .05

Table 16: Two-Way ANOVA Treadmill Exercise in Male Subjects

APPENDIX Q

POST HOC COMPARISON FOR TREADMILL RESPONSES IN FEMALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1min1	4.1108	12	.67833	.19582
	St1min2	3.8933	12	.88703	.25606
Pair 2	St2min1	5.2325	12	.86910	.25089
	St2min2	5.6242	12	1.18630	.34245
Pair 3	St3min1	5.6592	12	.92896	.26817
	St3min2	7.0142	12	1.76580	.50974
Pair 4	St4min1	7.6975	12	1.58511	.45758
	St4min2	9.9225	12	2.38629	.68886

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	St1min1 - St1min2	.21750	.67533	.19495	-.21159	.64659	1.116	11	.288
Pair 2	St2min1 - St2min2	-.39167	.70790	.20435	-.84145	.05811	-1.917	11	.082
Pair 3	St3min1 - St3min2	-1.35500	1.46645	.42333	-2.28674	-.42326	-3.201	11	.008
Pair 4	St4min1 - St4min2	-2.22500	1.72842	.49895	-3.32319	-1.12681	-4.459	11	.001

Table 17: *Post hoc* Comparison for Cycle Ergometer Responses in Female Subjects

APPENDIX R

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR MALE SUBJECTS

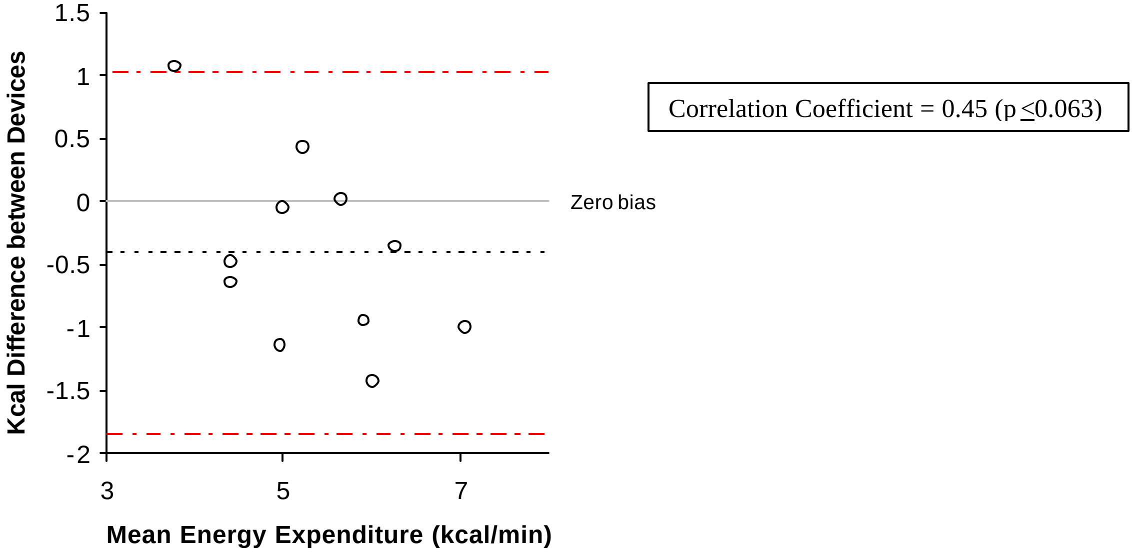


Figure 36: Bland-Altman Plot Treadmill Exercise Stage 2 for Male Subjects

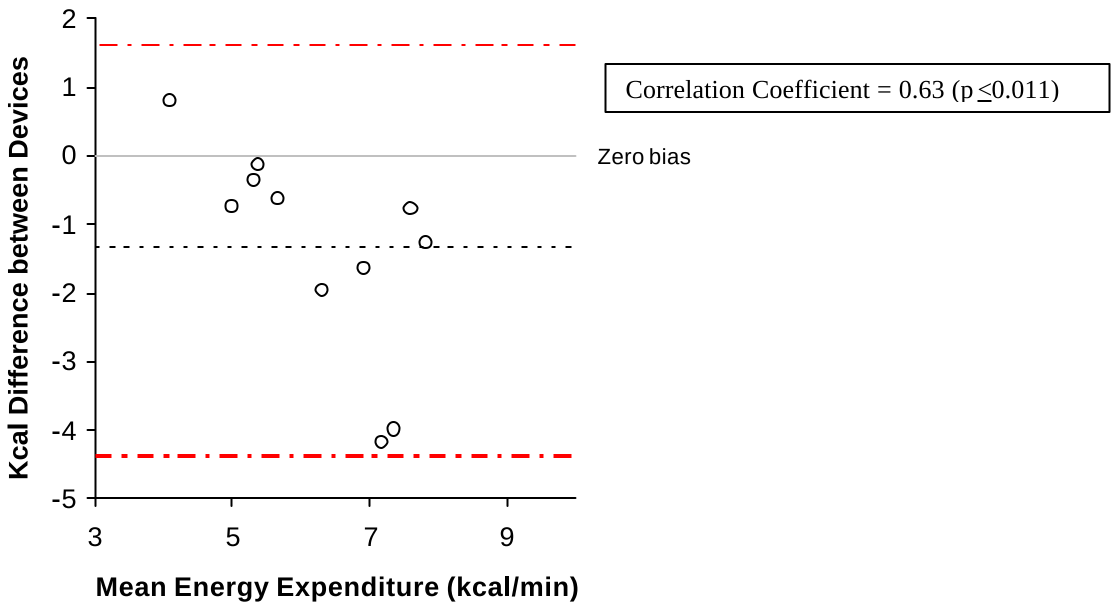


Figure 37: Bland-Altman Plot Treadmill Exercise Stage 3 for Male Subjects

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR MALE SUBJECTS

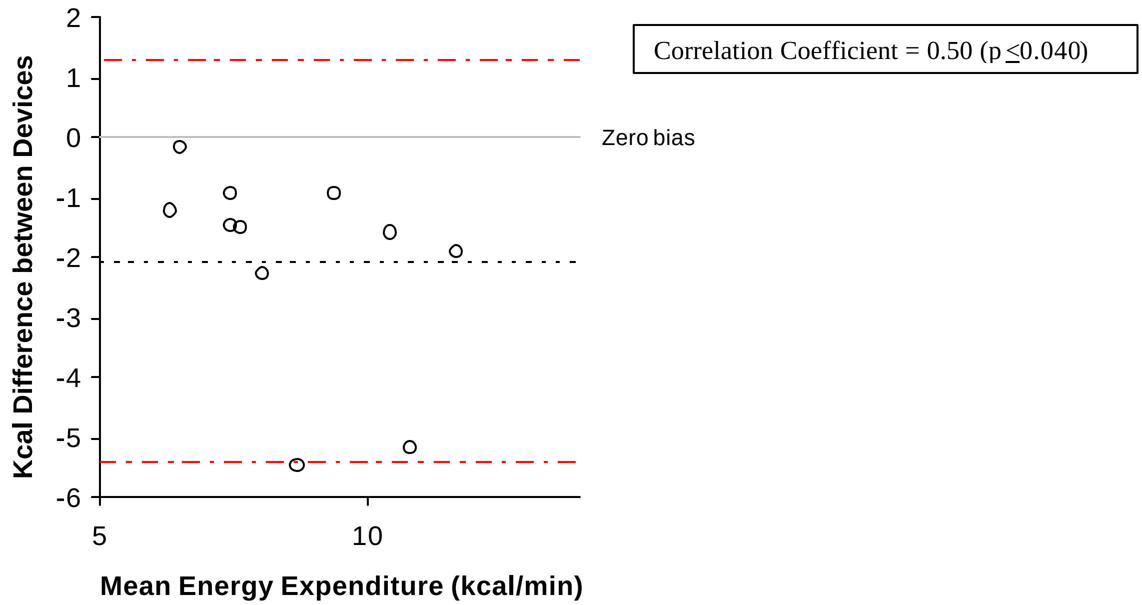


Figure 38: Bland-Altman Plot Treadmill Exercise Stage 4 for Male Subjects

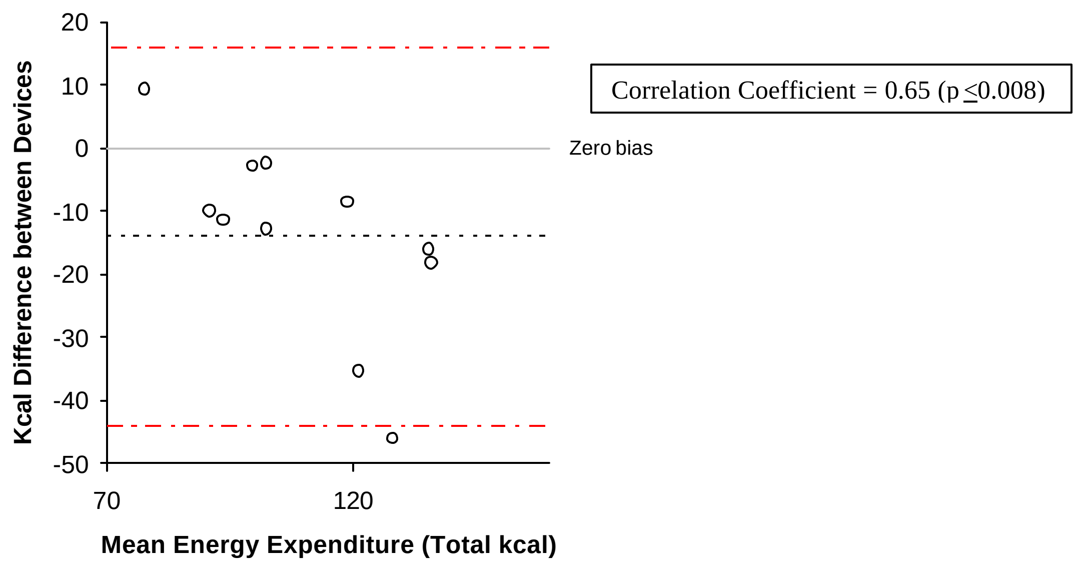


Figure 39: Bland-Altman Plot Treadmill Exercise Total Energy Expenditure for Male Subject

APPENDIX S

INTRACLASS CORRELATION FOR TREADMILL ENERGY EXPENDITURE IN MALE SUBJECTS

Stage 1: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.630(b)	.145	.875	4.468	11.0	11	.010
Average Measures	.773(c)	.253	.934	4.468	11.0	11	.010

Stage 2: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.731(b)	.300	.914	7.631	11.0	11	.001
Average Measures	.844(c)	.447	.955	7.631	11.0	11	.001

Stage 3: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.325(b)	-.129	.719	2.702	11.0	11	.057
Average Measures	.490(c)	-.420	.844	2.702	11.0	11	.057

Stage 4: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.404(b)	-.121	.784	4.494	11.0	11	.010
Average Measures	.576(c)	-.366	.885	4.494	11.0	11	.010

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 18: Intraclass correlation for Treadmill Exercise in Male Subjects

APPENDIX T

TWO-WAY ANOVA ENERGY EXPENDITURE DURING CYCLE ERGOMETER EXERCISE IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1.1min	1.6022	.56651	23
St1.2min	3.1300	.41283	23
St2.1min	2.0252	1.05131	23
St2.2min	4.5104	.52933	23

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	18.702	1	40.545	.000	.648	1.000
	Greenhouse-Geisser	18.702	1.000	40.545	.000	.648	1.000
	Huynh-Feldt	18.702	1.000	40.545	.000	.648	1.000
	Lower-bound	18.702	1.000	40.545	.000	.648	1.000
Error(time)	Sphericity Assumed	10.148	22				
	Greenhouse-Geisser	10.148	22.000				
	Huynh-Feldt	10.148	22.000				
	Lower-bound	10.148	22.000				
device	Sphericity Assumed	92.601	1	201.535	.000	.902	1.000
	Greenhouse-Geisser	92.601	1.000	201.535	.000	.902	1.000
	Huynh-Feldt	92.601	1.000	201.535	.000	.902	1.000
	Lower-bound	92.601	1.000	201.535	.000	.902	1.000
Error(device)	Sphericity Assumed	10.109	22				
	Greenhouse-Geisser	10.109	22.000				
	Huynh-Feldt	10.109	22.000				
	Lower-bound	10.109	22.000				
time * device	Sphericity Assumed	5.270	1	30.820	.000	.583	1.000
	Greenhouse-Geisser	5.270	1.000	30.820	.000	.583	1.000
	Huynh-Feldt	5.270	1.000	30.820	.000	.583	1.000
	Lower-bound	5.270	1.000	30.820	.000	.583	1.000
Error(time*device)	Sphericity Assumed	3.762	22				
	Greenhouse-Geisser	3.762	22.000				

a Computed using alpha = .05

Table 19: Two-Way ANOVA for Cycle Ergometer Exercise in the Combined Group of Female and Male Subjects

APPENDIX U

POST HOC COMPARISON FOR CYCLE ERGOMETER RESPONSES IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1.1min	1.6022	23	.56651	.11813
	St1.2min	3.1300	23	.41283	.08608
Pair 2	St2.1min	2.0252	23	1.05131	.21921
	St2.2min	4.5104	23	.52933	.11037

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	St1.1min - St1.2min	-1.52783	.59951	.12501	-1.78708	-1.26858	-12.222	22	.000
Pair 2	St2.1min - St2.2min	-2.48522	.94950	.19798	-2.89581	-2.07462	-12.553	22	.000

Table 20: *Post hoc* Comparison for Cycle Ergometer Responses in the Combined Group of Female and Male Subjects

APPENDIX V

BLAND-ALTMAN PLOT CYCLE ERGOMETER RESPONSES FOR THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

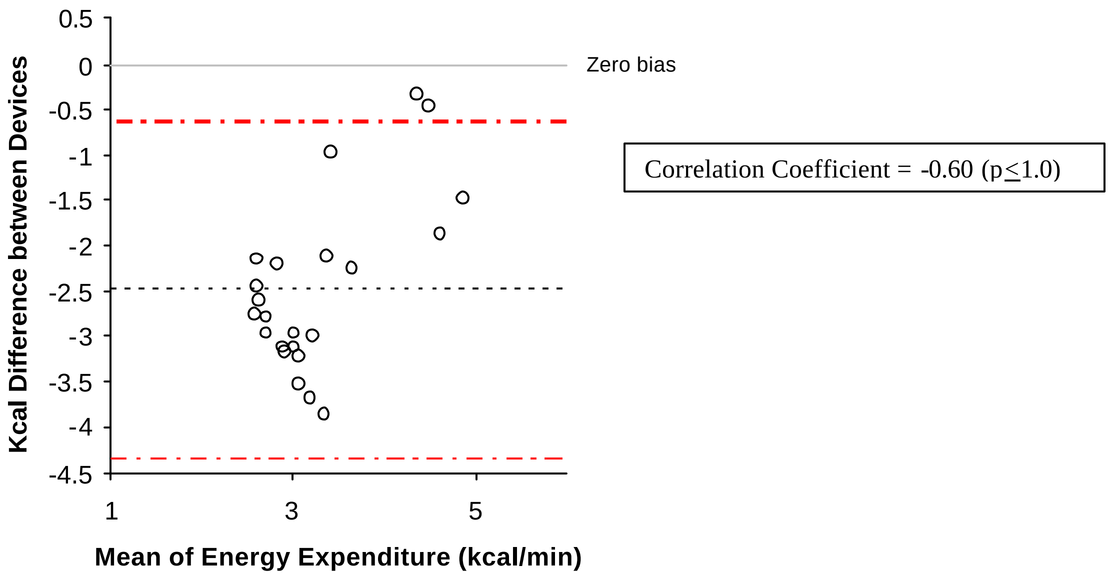


Figure 40: Bland-Altman Plot Cycle Ergometer Exercise Stage 2 for the Combined Group of Female and Male Subjects

APPENDIX W

INTRACLASS CORRELATION FOR CYCLE ERGOMETER ENERGY EXPENDITURE IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Stage 1: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.047(b)	-.045	.219	1.734	22.0	22	.102
Average Measures	.090(c)	-.125	.410	1.734	22.0	22	.102

Stage 2: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.064(b)	-.048	.273	2.073	22.0	22	.047
Average Measures	.121(c)	-.127	.476	2.073	22.0	22	.047

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 21: Intraclass correlation for Cycle Ergometer Exercise in Female and Male Subjects

APPENDIX X

TWO-WAY ANOVA ENERGY EXPENDITURE DURING TREADMILL EXERCISE IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Descriptive Statistics

	Mean	Std. Deviation	N
St1min1	4.0204	.53078	24
St1min2	4.2392	.88106	24
St2min1	5.1142	.64935	24
St2min2	5.9796	1.03218	24
St3min1	5.6096	.71121	24
St3min2	7.7371	1.52397	24
St4min1	7.4513	1.36974	24
St4min2	10.4179	1.88852	24

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared	Observed Power(a)
time	Sphericity Assumed	593.070	3	344.019	.000	.937	1.000
	Greenhouse-Geisser	593.070	1.725	344.019	.000	.937	1.000
	Huynh-Feldt	593.070	1.852	344.019	.000	.937	1.000
	Lower-bound	593.070	1.000	344.019	.000	.937	1.000
Error(time)	Sphericity Assumed	39.651	69				
	Greenhouse-Geisser	39.651	39.675				
	Huynh-Feldt	39.651	42.595				
	Lower-bound	39.651	23.000				
device	Sphericity Assumed	114.515	1	56.888	.000	.712	1.000
	Greenhouse-Geisser	114.515	1.000	56.888	.000	.712	1.000
	Huynh-Feldt	114.515	1.000	56.888	.000	.712	1.000
	Lower-bound	114.515	1.000	56.888	.000	.712	1.000
Error(device)	Sphericity Assumed	46.299	23				
	Greenhouse-Geisser	46.299	23.000				
	Huynh-Feldt	46.299	23.000				
	Lower-bound	46.299	23.000				
time * device	Sphericity Assumed	54.975	3	67.469	.000	.746	1.000
	Greenhouse-Geisser	54.975	1.827	67.469	.000	.746	1.000
	Huynh-Feldt	54.975	1.976	67.469	.000	.746	1.000
	Lower-bound	54.975	1.000	67.469	.000	.746	1.000
Error(time*device)	Sphericity Assumed	18.741	69				
	Greenhouse-Geisser	18.741	42.018				
	Huynh-Feldt	18.741	45.455				

a Computed using alpha = .05

Table 22: Two-Way ANOVA for Treadmill Exercise in the Combined Group of Female and Male Subjects

APPENDIX Y

POST HOC COMPARISON FOR TREADMILL RESPONSES IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	St1min1	4.0204	24	.53078	.10834
	St1min2	4.2392	24	.88106	.17985
Pair 2	St2min1	5.1142	24	.64935	.13255
	St2min2	5.9796	24	1.03218	.21069
Pair 3	St3min1	5.6096	24	.71121	.14517
	St3min2	7.7371	24	1.52397	.31108
Pair 4	St4min1	7.4512	24	1.36974	.27960
	St4min2	10.4179	24	1.88852	.38549

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-.21875	.75040	.15317	-.53562	.09812	-1.428	23	.167
-.86542	.84006	.17148	-1.22014	-.51069	-5.047	23	.000
-2.12750	1.40154	.28609	-2.71932	-1.53568	-7.437	23	.000
-2.96667	1.55644	.31771	-3.62389	-2.30944	-9.338	23	.000

Table 23: *Post hoc* Comparison for Treadmill Responses in the Combined Group of Female and Male Subjects

APPENDIX Z

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

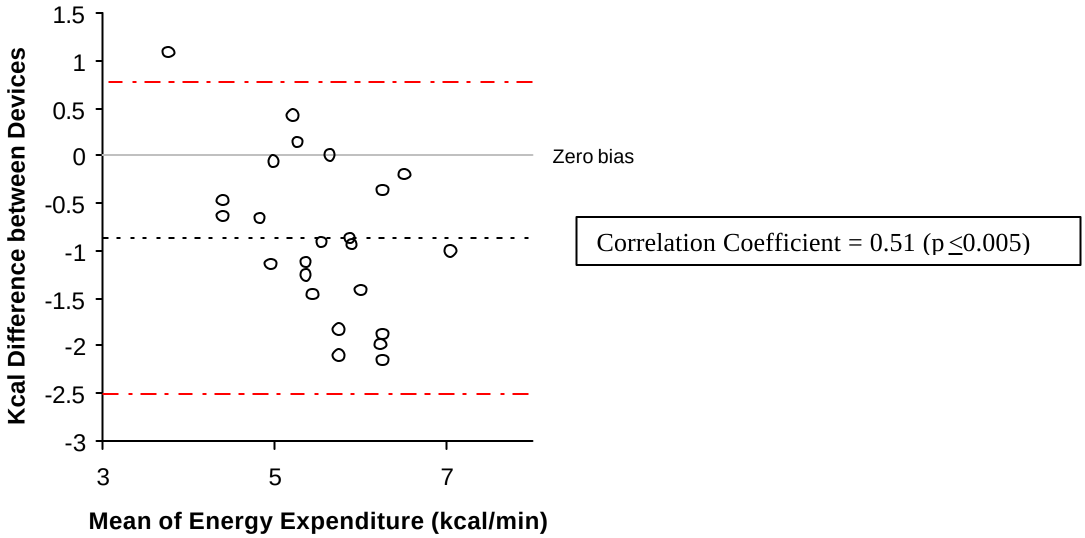


Figure 41: Bland-Altman Plot Treadmill Exercise Stage 2 for the Combined Group of Female and Male Subjects

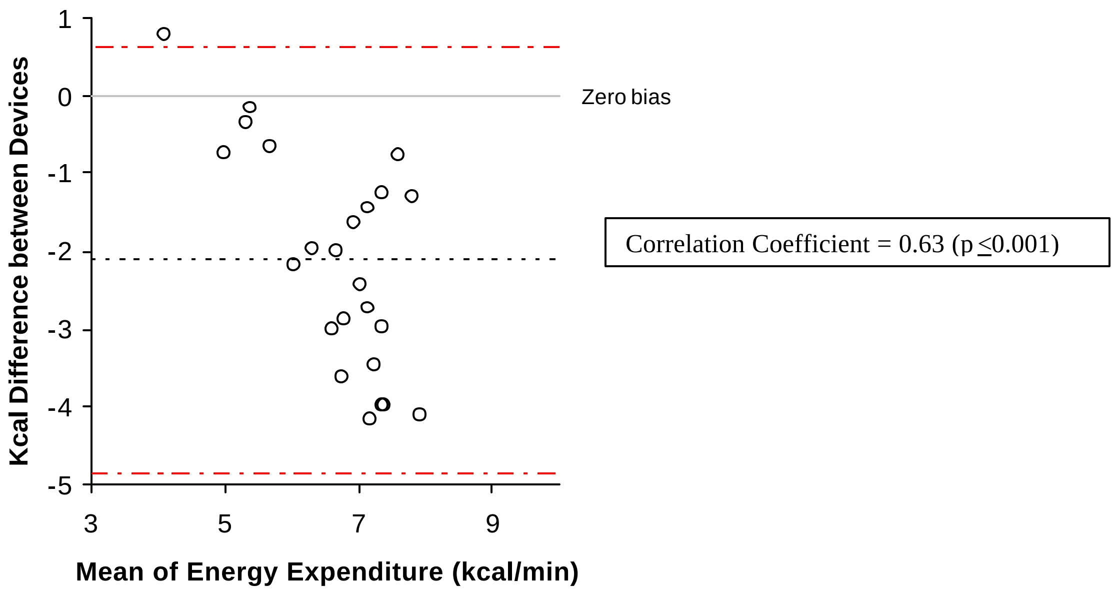


Figure 42: Bland-Altman Plot Treadmill Exercise Stage 3 for the Combined Group of Female and Male Subjects

BLAND-ALTMAN PLOT TREADMILL RESPONSES FOR THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

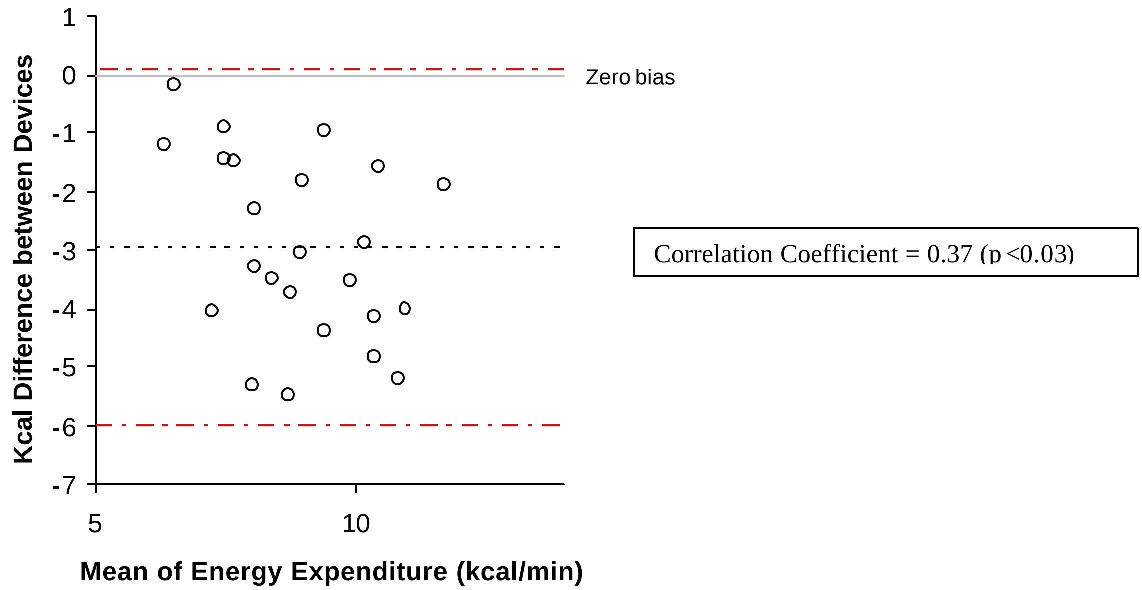


Figure 43: Bland-Altman Plot Treadmill Exercise Stage 4 for the Combined Group of Female and Male Subjects

APPENDIX AA

INTRACLASS CORRELATION FOR CYCLE ERGOMETER ENERGY EXPENDITURE IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Stage 1: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.457(b)	.090	.719	2.758	23.0	23	.009
Average Measures	.628(c)	.164	.837	2.758	23.0	23	.009

Stage 2: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.354(b)	-.080	.676	3.214	23.0	23	.003
Average Measures	.523(c)	-.314	.820	3.214	23.0	23	.003

Stage 3: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.119(b)	-.090	.398	1.880	23.0	23	.069
Average Measures	.212(c)	-.288	.661	1.880	23.0	23	.069

Stage 4: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.214(b)	-.088	.567	3.493	23.0	23	.002
Average Measures	.352(c)	-.234	.746	3.493	23.0	23	.002

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 24: Intraclass correlation for Treadmill Exercise in Female and Male Subjects

APPENDIX BB

DEPENDENT t TEST FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female Subjects

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotExAB	19.1208	12	7.05017	2.03521
	TotEXRM	39.8017	12	4.62234	1.33435

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 TotExAB - TotEXRM	-20.68083	7.86627	2.27080	-25.67882	-15.68285	-9.107	11	.000

Male Subjects

Paired Samples Statistic

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotExAB	22.4200	11	5.93120	1.78832
	TotExRM	39.8282	11	4.60767	1.38926

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 TotExAB - TotExRM	-17.40818	6.87309	2.07231	-22.02558	-12.79078	-8.400	10	.000

APPENDIX BB (continued)

DEPENDENT t TEST FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female & Male Subjects

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ABExTot	20.6987	23	6.60927	1.37813
	RMExTot	39.8143	23	4.50926	.94025

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 ABExTot - RMExTot	-19.11565	7.43004	1.54927	-22.32864	-15.90266	-12.338	22	.000

Table 25: Dependent t Test for Cycle Ergometer Total Energy Expenditure

APPENDIX CC

INTRACLASS CORRELATION FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female Subjects

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.019(b)	-.043	.185	1.297	11.0	11	.337
Average Measures	.037(c)	-.104	.334	1.297	11.0	11	.337

Males Subjects

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.026(b)	-.047	.227	1.388	10.0	10	.307
Average Measures	.050(c)	-.118	.395	1.388	10.0	10	.307

Female & Males Subjects

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.021(b)	-.037	.134	1.319	22.0	22	.261
Average Measures	.040(c)	-.100	.271	1.319	22.0	22	.261

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 26: Intraclass correlation for Cycle Ergometer Total Energy Expenditure

APPENDIX DD

DEPENDENT t TEST FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExerTime 1	102.4908	12	11.46967	3.31101
	ExerTime 2	134.9842	12	12.80614	3.69681

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-32.49333	8.58342	2.47782	-37.94698	-27.03969	-13.114	11	.000

Male

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExerTime 1	104.6533	12	15.97401	4.61130
	ExerTime 2	119.4733	12	25.72386	7.42584

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-14.82000	14.87983	4.29544	-24.27419	-5.36581	-3.450	11	.005

APPENDIX DD (continued)

DEPENDENT t TEST FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female & Male Combined

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExerTime 1	103.5721	24	13.64456	2.78518
	ExerTime 2	127.2288	24	21.39319	4.36687

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-23.65667	14.92009	3.04555	-29.95687	-17.35647	-7.768	23	.000

Table 27: Dependent t Test for Treadmill Total Energy Expenditure

APPENDIX EE

INTRACLASS CORRELATION FOR CYCLE ERGOMETER TOTAL ENERGY EXPENDITURE

Female Subjects: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.137(b)	-.025	.511	7.017	11.0	11	.002
Average Measures	.241(c)	-.054	.688	7.017	11.0	11	.002

Male Subjects: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.622(b)	-.017	.885	7.282	11.0	11	.001
Average Measures	.767(c)	-.118	.941	7.282	11.0	11	.001

Combined Female and Male Subjects: **Intraclass Correlation Coefficient**

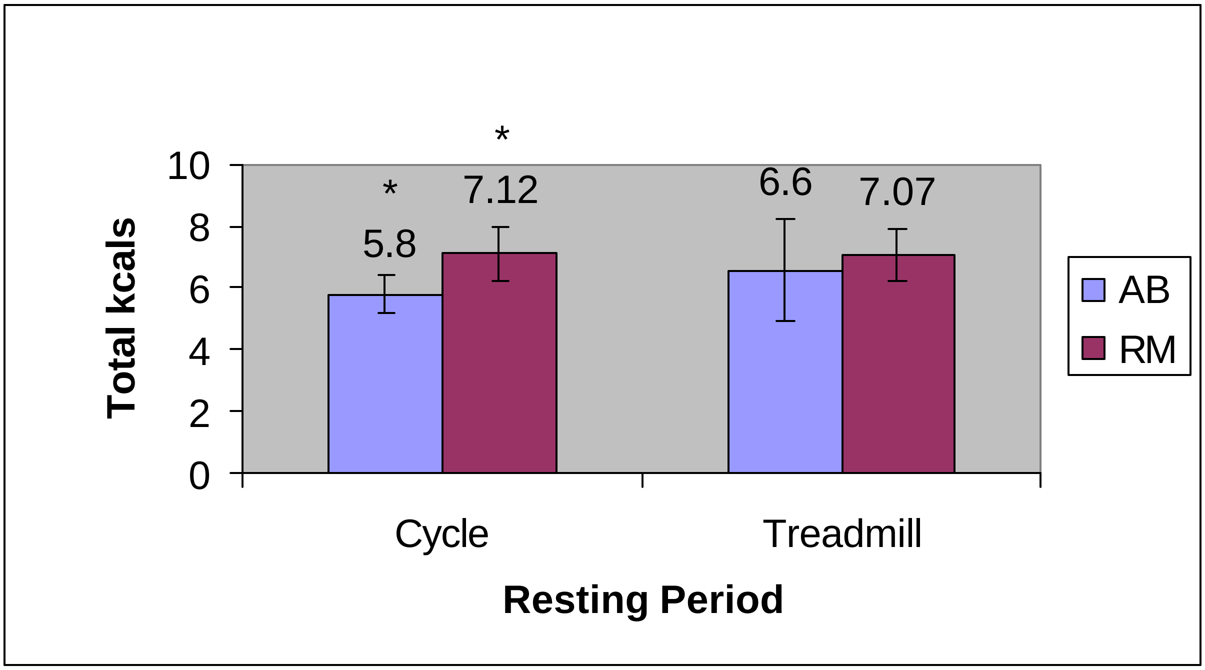
	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.353(b)	-.106	.710	4.785	23.0	23	.000
Average Measures	.522(c)	-.297	.841	4.785	23.0	23	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 28: Intraclass correlation for Cycle Ergometer Total Energy Expenditure

APPENDIX FF

RESTING ENERGY EXPENDITURE (KCALS) IN FEMALE SUBJECTS



*(P < 0.001)

Figure 44: Resting Energy Expenditure (Kcals) in Female Subjects

APPENDIX GG

DEPENDENT t TEST FOR RESTING ENERGY EXPENDITURE IN FEMALE SUBJECTS

Prior to Cycle Ergometer Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	rest1min	1.2732	23	.30201	.06297
	rest2min	1.4256	23	.22263	.04642
Pair 2	rest.1	6.3661	23	1.51003	.31486
	rest.2	7.1278	23	1.11317	.23211

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-.15235	.37392	.07797	-.31404	.00935	-1.954	22	.064
-.76174	1.86962	.38984	-1.57022	.04674	-1.954	22	.064

Prior to Treadmill Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	rest1min	1.2905	24	.28961	.05912
	rest2min	1.3980	24	.20496	.04184
Pair 2	rest.1	6.4525	24	1.44805	.29558
	rest.2	6.9900	24	1.02480	.20919

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-.10750	.25919	.05291	-.21695	.00195	-2.032	23	.054
-.53750	1.29595	.26453	-1.08473	.00973	-2.032	23	.054

Table 29: Dependent t Test for Resting Energy Expenditure in Female Subjects

APPENDIX HH

BLAND-ALTMAN PLOT RESTING ENERGY EXPENDITURE RESPONSES PRIOR TO TREADMILL EXERCISE IN FEMALE SUBJECTS

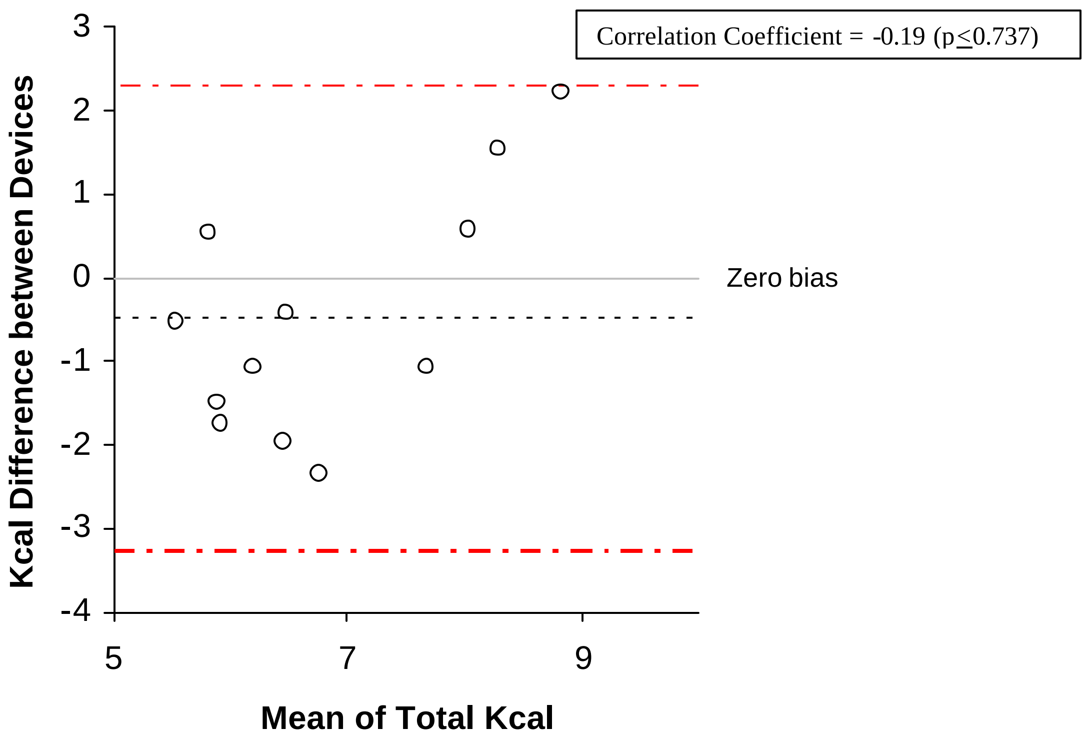


Figure 45: Bland-Altman Plot Resting Energy Expenditure Responses Prior to Treadmill Exercise in Female Subjects

APPENDIX II

INTRACLASS CORRELATION FOR RESTING ENERGY EXPENDITUE IN FEMALE SUBJECTS

Prior to Cycle Ergometer Exercise: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.006(b)	-.340	.382	1.014	22.0	22	.487
Average Measures	.012(c)	-1.028	.553	1.014	22.0	22	.487

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Prior to Treadmill Exercise: **Intraclass Correlation Coefficient**

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.400(b)	-.161	.776	2.376	11.0	11	.083
Average Measures	.572(c)	-.382	.874	2.376	11.0	11	.083

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 30: Intraclass correlation for Resting Energy Expenditure in Female Subjects

APPENDIX JJ

RESTING ENERGY EXPENDITURE (KCALS) IN MALE SUBJECTS

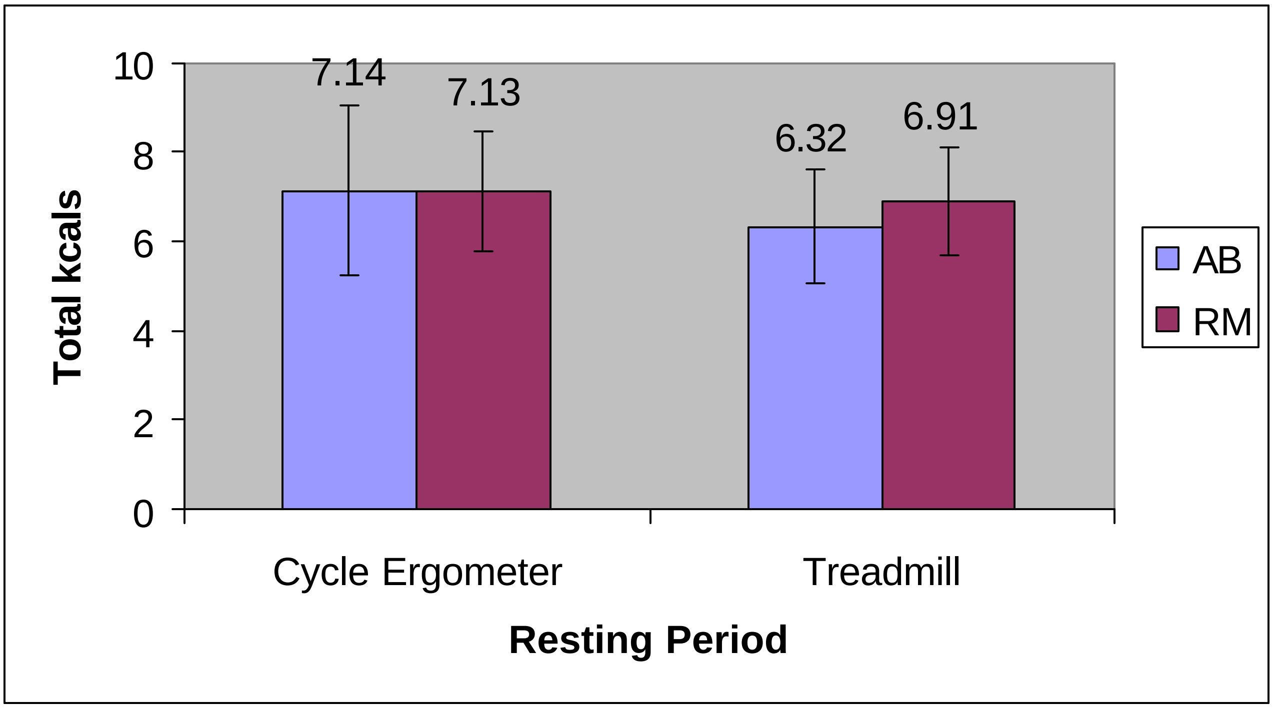


Figure 46: Resting Energy Expenditure (Kcals) in Male Subjects

APPENDIX KK

DEPENDENT t TEST FOR RESTING ENERGY EXPENDITURE IN MALE SUBJECTS

Prior to Cycle Ergometer Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RestABmin	1.4280	11	.38125	.11495
	RestRMmin	1.4262	11	.27087	.08167
Pair 2	RestAB	7.1400	11	1.90627	.57476
	RestRM	7.1309	11	1.35436	.40835

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	RestABmin - RestRMmin	.00182	.47551	.14337	-.31763	.32127	.013	10	.990
Pair 2	RestAB - RestRM	.00909	2.37753	.71685	-1.58816	1.60634	.013	10	.990

Prior to Treadmill Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	restABmin	1.2643	12	.25181	.07269
	restRMmin	1.3827	12	.24329	.07023
Pair 2	rest.1	6.3217	12	1.25905	.36346
	rest.2	6.9133	12	1.21647	.35117

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	restABmin - restRMmin	-.11833	.24104	.06958	-.27148	.03481	-1.701	11	.117
Pair 2	rest.1 - rest.2	-.59167	1.20518	.34791	-1.35740	.17407	-1.701	11	.117

Table 31: Dependent t Test for Resting Energy Expenditure in Male Subjects

APPENDIX LL

BLAND-ALTMAN PLOT RESTING ENERGY EXPENDITURE RESPONSES PRIOR TO TREADMILL EXERCISE IN MALE SUBJECTS

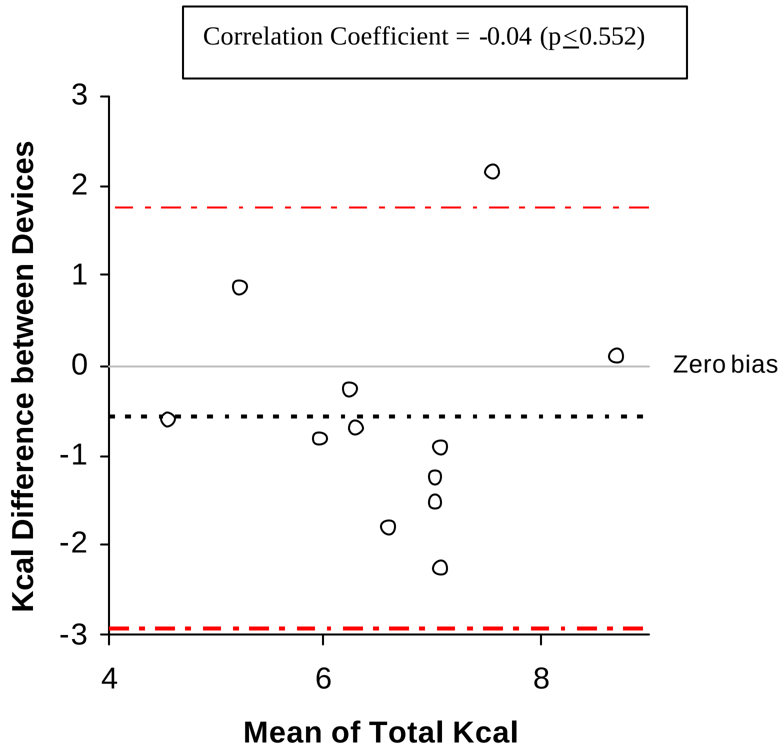


Figure 47: Bland-Altman Plot Resting Energy Expenditure Responses Prior to Treadmill Exercise in Male Subjects

APPENDIX MM

INTRACLASS CORRELATIONS FOR RESTING ENERGY EXPENDITURE IN MALE SUBJECTS

Prior to Cycle Ergometer Exercise: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	-.037(b)	-.700	.576	.935	10.0	10	.541
Average Measures	-.077(c)	-4.661	.731	.935	10.0	10	.541

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Prior to Treadmill Exercise: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.490(b)	-.023	.814	3.220	11.0	11	.032
Average Measures	.657(c)	-.070	.898	3.220	11.0	11	.032

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 32: Intraclass correlation for Resting Energy Expenditure in Male Subjects

APPENDIX NN

RESTING ENERGY EXPENDITURE (KCALS) IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

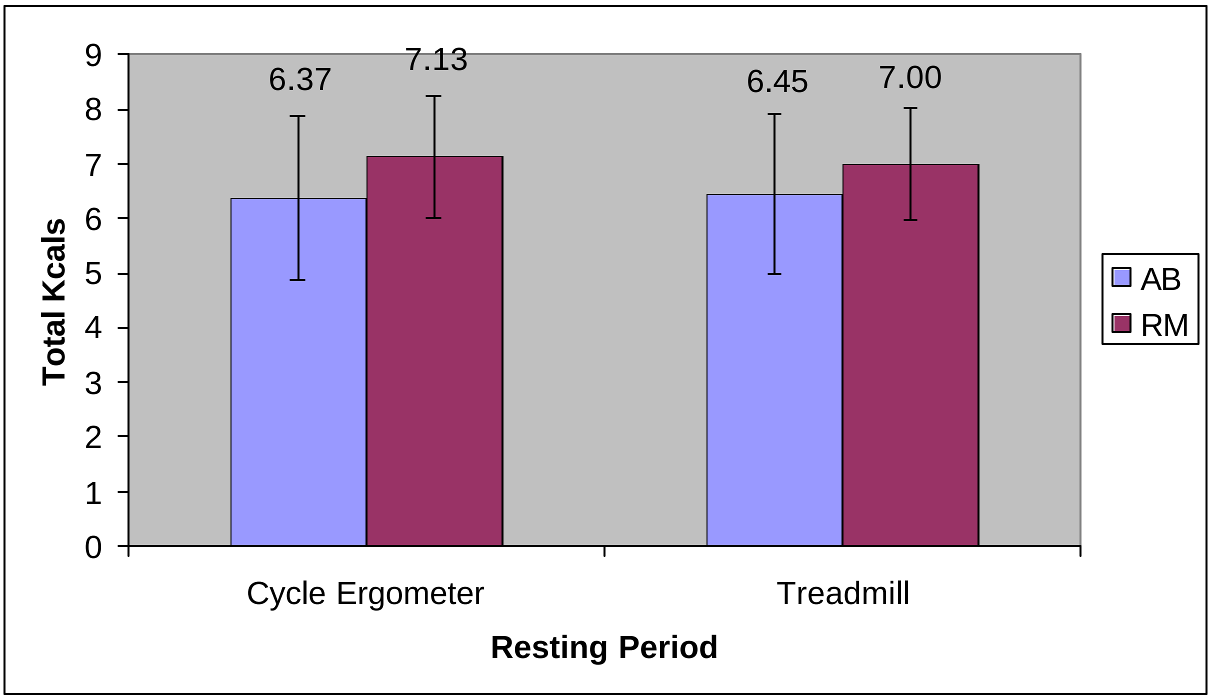


Figure 48: Resting Energy Expenditure (Kcals) in the Combined Group of Female and Male Subjects

APPENDIX OO

DEPENDENT t TEST FOR RESTING ENERGY EXPENDITURE IN THE COMBINED GROUP OF FEMALE AND MALE SUBJECTS

Prior to Cycle Ergometer Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	rest1min	1.2732	23	.30201	.06297
	rest2min	1.4256	23	.22263	.04642
Pair 2	rest.1	6.3661	23	1.51003	.31486
	rest.2	7.1278	23	1.11317	.23211

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-.15235	.37392	.07797	-.31404	.00935	-1.954	22	.064
-.76174	1.86962	.38984	-1.57022	.04674	-1.954	22	.064

Prior to Treadmill Exercise

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	rest1min	1.2905	24	.28961	.05912
	rest2min	1.3980	24	.20496	.04184
Pair 2	rest.1	6.4525	24	1.44805	.29558
	rest.2	6.9900	24	1.02480	.20919

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
			Lower	Upper			
-.10750	.25919	.05291	-.21695	.00195	-2.032	23	.054
-.53750	1.29595	.26453	-1.08473	.00973	-2.032	23	.054

Table 33: Dependent t Test for Resting Energy Expenditure in the Combined Group of Female and Male Subjects

APPENDIX PP

BLAND-ALTMAN PLOT RESTING ENERGY EXPENDITURE RESPONSES IN FEMALE AND MALE SUBJECTS

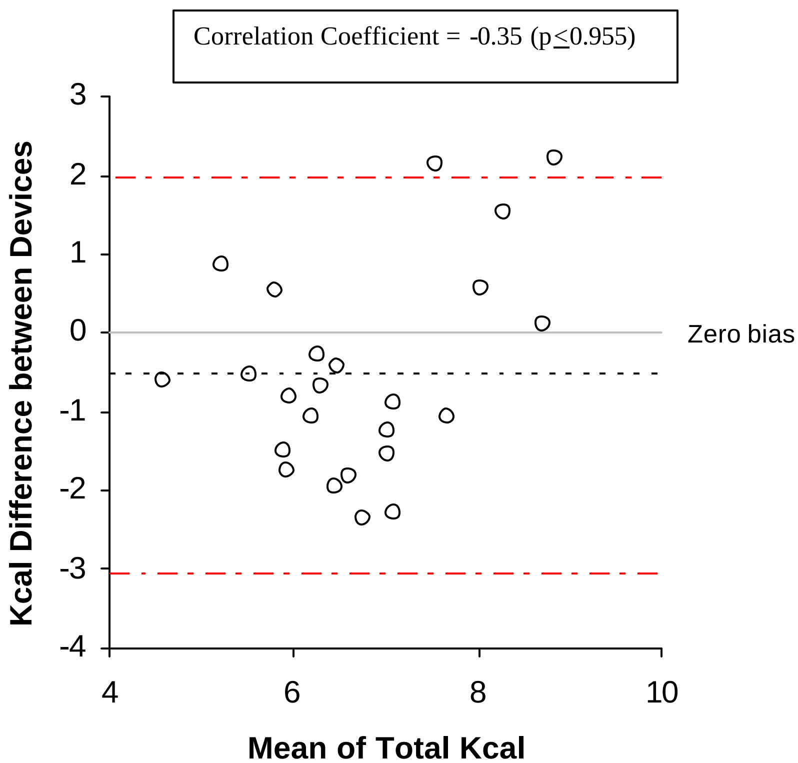


Figure 49: Bland-Altman Plot Resting Energy Expenditure Responses in Female and Male Subjects

APPENDIX QQ

INTRACLASS CORRELATION FOR RESTING ENERGY EXPENDITURE IN FEMALE AND MALE SUBJECTS

Prior to Cycle Ergometer Exercise: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.006(b)	-.340	.382	1.014	22.0	22	.487
Average Measures	.012(c)	-1.028	.553	1.014	22.0	22	.487

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Prior to Treadmill Exercise: Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.436(b)	.073	.704	2.748	23.0	23	.009
Average Measures	.607(c)	.119	.828	2.748	23.0	23	.009

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 34: Intraclass correlation for Resting Energy Expenditure Prior to Exercise in Female and Male Subjects

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