

Actical Accelerometry Cut-points for Quantifying Levels of Exertion in Overweight
Adults

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ABSTRACT

Jamie Giffuni: Actical accelerometry cut-points for quantifying levels of exertion in overweight adults
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The purpose of this study was to develop Actical count cut-points for overweight adults that correspond to moderate and vigorous intensity exercise. The standard definitions of moderate (3 METS) and vigorous (6 METS) were used. Cut-points in overweight subjects (OW) were also compared to cut-points in normal weight (NW) subjects. Thirty overweight (BMI >25 kg/m²) male and female adults completed a progressive submaximal exercise session on a treadmill while oxygen uptake was measured. The activity count cut-point derived from ROC curves for moderate intensity was 1839 for OW and 1994 for NW and cut-points for vigorous intensity were 3900 for OW and 4381 for NW. Activity count thresholds were greater in the NW compared to the OW subjects at both moderate and vigorous intensities.

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CHAPTER I

INTRODUCTION

Introduction

Approximately 67% of adults in the United States are overweight and 34% are obese as indicated by a body mass index (BMI) greater than 25 kg/m² and 30 kg/m², respectively (Health, 2008). Overweight and obesity increase risk for developing hypertension, type 2 diabetes, dyslipidemia, coronary artery and heart disease, and stroke (Strath et al., 2008). Obesity is often the result of long term positive energy balance, which is often due to prolonged excess energy intake and/or insufficient energy expenditure (Murdy & Ehrman, 2009). Physical activity is important for overweight and obese individuals because it is a major component of energy expenditure, and subsequently, weight control (Jakicic & Otto, 2005). Cross sectional evidence indicates that an inverse relationship exists between BMI and physical activity (Donnelly et al., 2009). Therefore, overweight or obese individuals should strive to meet the recommendations for physical activity to benefit weight control and their health.

The American College of Sports Medicine (ACSM) recommends that physical activity results in an energy expenditure of greater than 2,000 kcal per week to promote and maintain weight loss (Donnelly et al., 2009). The frequency, intensity, duration, and mode of activity are all important as part of the manipulation of energy expenditure (ACSM, 2010). Moderate intensity exercise is considered to be the minimal threshold of intensity for improving health (Jakicic, 2003). Further, thirty minutes of moderate-to-

vigorous intensity physical activity (MVPA) per day, five days per week (total 150 minutes per week) has been shown to improve a previously sedentary individual's health (Jakicic, 2003). However, 45 to 60 minutes per day of MVPA on five days per week (total 300 minutes per week) may be most effective for improving weight loss and preventing weight regain after weight loss in overweight and obese adults (Jakicic, 2003; Jakicic & Otto, 2005). Thus, it becomes important to be able to quantify MVPA in the overweight and obese population to determine if an individual is meeting the recommended intensity of physical activity.

There are several different ways to measure exercise intensity. Perhaps the most common method is the use of metabolic equivalents (METs). A MET is the ratio of work metabolic rate to the standard resting metabolic rate of 1 MET: 1 MET = 3.5 mL O₂/kg/min (Ainsworth et al., 2000; Hendelman et al., 2000). Light exercise is defined as <3 METs, moderate as 3-5.99 METs, and vigorous as ≥6 METs. These cut-points have been used by research studies when attempting to quantify the exercise intensity of subjects (Lee et al., 1995).

The ability to measure physical activity is an important aspect of obesity research. There are many different ways to assess an individual's physical activity: self-report, pedometers, heart rate monitoring, indirect calorimetry, and accelerometry. The self-report and pedometer methods, while being fairly inexpensive and easy to use, tend to be subjective and insensitive, respectively (Reiser et al., 2009). Heart rate monitoring is an objective measure of physical activity and is linearly related to energy expenditure; however, there is high inter-individual variability and limited accuracy using this method (Reiser & Schlenk, 2009). Indirect calorimetry involves expensive equipment and may

not be well tolerated by research subjects. Accelerometry is an objective measurement of physical activity that allows researchers to track the amount and intensity of physical activity of their subjects (Crouter & Bassett, 2008). There are many different manufacturers of accelerometers, and while this increases availability, devices are not inter-changeable due to variations in sensitivity and calibration equations (Welk, 2005). Cut-points, or thresholds separating different intensities, have been developed for various accelerometer devices. These cut-points allow researchers to objectively determine if a subject has met the recommendations for moderate-to-vigorous intensity exercise. Specific calibration studies have been completed on children, adolescents, and adults (Fairweather et al., 1999; Puyau et al., 2002; Puyau et al., 2004; Treuth et al., 2004). However, it is known that height, weight, body fatness, and economy of movement patterns all have the potential to affect accelerometer output (Welk, 2005). Therefore, research in the overweight and obese population with specific accelerometer devices is needed.

The Actical accelerometer is becoming widely used in physical activity research (Crouter & Bassett, 2008). The Actical is an omni-directional, small (28 x 27 x 10 cm), lightweight (17 g) accelerometer that can collect data in 15 s epochs (Crouter & Bassett, 2008). Regression equations to estimate energy expenditure from activity counts were originally developed using 24 normal weight adults and provided reasonable predictions of MET levels (Klippel & Heil, 2003). Recently, more precise regression models have been developed to predict METs from counts per minute (Crouter & Bassett, 2008). However, these subjects had an average BMI of 24.2 kg/m². Neither research study presented cut-points for moderate and vigorous intensity exercise. Therefore, research is

needed in the overweight and obese population to determine cut-points for exercise intensity using the Actical accelerometer.

Purpose

The primary purpose of this study was to develop cut-points using the Actical accelerometer which correspond to moderate and vigorous intensity exercise in overweight or obese adults using the METs methods of classifying intensity. The secondary purpose was to compare the cut-points developed for overweight and obese adults with those developed for normal weight adults using the Actical accelerometer (Diaz, 2009).

Hypotheses

The primary purpose of this study did not involve a specific hypothesis. To address the secondary purpose, it was hypothesized that there would be no difference in cut-points between overweight and obese adults compared to normal weight adults.

Definition of Terms

1. Accelerometer counts: the resultant outcome data from an accelerometer, which is the product of frequency and intensity of movement, taken at set intervals (Tudor-Locke & Meyers, 2001).
2. Cut-point: a threshold which establishes a difference between two conditions.
3. Overweight: an individual with a BMI between 25.0 and 29.9 kg/m² (CDC, 2009).
4. Obese: an individual with a BMI ≥ 30 kg/m² (CDC, 2009).
5. Calibration: “the process used to convert raw accelerometer counts into

more meaningful and interpretable units” (Welk, 2005).

Delimitations

1. Only two Actical monitors were used by subjects of this study. Both were calibrated according to the manufacturer’s instructions and were found to record activity counts within the acceptable error range.
2. The subjects will be overweight or obese male and female adults (BMI > 25 kg/m²).

Limitations

1. The relationship of accelerometer cut-points to energy expenditure depends on the type of activity being performed, and therefore, it may be unsuitable to apply cut-points developed in a laboratory setting to activities of daily living (Hendelman et al., 2000).
2. Two different instruments to measure oxygen uptake were used for normal and overweight subjects (Parvo Medics TrueMax 2400 Metabolic Measurement System and COSMED K4b² portable measurement system, respectively). However, both systems were calibrated against each other to ensure both systems measured oxygen uptake consistently.
3. Resting VO₂ was only recorded for two minutes standing on the treadmill. Therefore, the measurement was likely higher than the subject’s true resting VO₂.

Significance

The health benefits of regular physical activity are well known, but it is estimated that 50.5% of adults in the United States are not meeting the recommended levels of physical activity (CDC, 2007). Moderate to vigorous intensity physical activity significantly improves health, even when weight loss from exercise is lower than expected (King et al., 2009). There are many different ways to quantify the intensity of exercise, and accelerometry is becoming a widely used method. However, accelerometer counts are not comparable between devices due to differences in machinery, sensitivity, and calibration equations. Devices are also not interchangeable between the populations they are used in due to the effect of height, weight, body fatness, and economy of movement patterns on accelerometer output (Welk, 2005). At present, the literature on accelerometry cut-points separating MVPA in the overweight and obese population is limited. Cut-points available for the overweight and obese population using the Actical accelerometer are even more incomplete. The results of the present study may enable researchers to objectively quantify an intervention's exercise intensity as moderate or vigorous when the Actical accelerometer is used. The cut-points determined could allow for comparisons to be made between studies which utilize the Actical accelerometer as an objective measure of exercise intensity

Chapter II

REVIEW OF LITERATURE

The health benefits of physical activity are widely known; however, not all adults are meeting the recommendations to benefit health. There are several ways to monitor the physical activity patterns of adults and each has their own advantages and disadvantages. Accelerometry is becoming a widely used method of measuring physical activity because it provides an objective assessment of activity frequency, intensity, and duration. The literature review will focus on the different tools to assess physical activity levels. The review will begin with an overview of why physical activity is important to improving the lives of adults. The recommendations for the amount of activity needed to acquire these benefits will then be explored. The next section of this review will center on classifying the intensity of physical activity to ensure individuals are meeting the guidelines of activity intensity to improve health. The most commonly used methods of monitoring physical activity will then be discussed with an outline of the advantages and disadvantages to their use presented. The majority of the review will focus on the use of accelerometry in monitoring physical activity and will present the current calibration literature. The review will conclude with a description of the Actical accelerometer and a summary of the recent calibration literature regarding its use.

Health Benefits of Physical Activity

Physical activity is defined as “bodily movement produced by skeletal muscle that requires energy expenditure” and produces overall health benefits (National Institute of

Health [NIH], 1996). Exercise, which is a type of physical activity, is defined as “a planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness” (NIH, 1996). While some people may believe that exercise is the only way to positively affect health outcomes, there is a large amount of literature to support an inverse association between total amounts of physical activity and all cause mortality in men and women (Bucksch, 2005). Physical activity protects against the development of cardiovascular disease (CVD) and also positively alters various CVD risk factors, including hypertension, insulin resistance, obesity, and high blood lipid levels (NIH, 1996). Physical activity is also promoted as an important weight management strategy by public health and scientific organizations including the National Heart Lung and Blood Institute (NHLBI), Center for Disease Control (CDC), American College of Sports Medicine (ACSM), and the American Medical Association (Donnelly et al., 2009). While it is known that physical activity relates to positive health outcomes, the amount of physical activity required to benefit health remains unclear.

The amount, or dose, of physical activity required to improve health can be manipulated by altering the duration, frequency, intensity, and mode of activity (Kesaniemi et al., 2001). There are several organizations with recommendations for physical activity but the ACSM recommendations are the most widely used. The ACSM physical activity guidelines have shifted over time from an earlier focus on higher intensity activity to achieve maximal gains in physical fitness to moderate intensity activities to improve health (ACSM, 2010). Moderate intensity activity is defined as exercise that “noticeably increases heart rate and breathing” and is classified as activities of 3 metabolic equivalents (METs), or three times the energy expended above resting

levels (ACSM, 2010). Vigorous intensity activity causes substantial increases in heart rate and breathing and is classified as 6 MET activities (ACSM, 2010). The current ACSM and CDC endorsed recommendations for aerobic physical activity for healthy adults aged 18-65 years old are to engage in at least 30 minutes of moderate intensity physical activity on five days per week or at least 20 minutes of vigorous activity on three days per week (Haskell et al., 2007). This recommended amount of activity is in addition to the light intensity activities of daily living routinely performed by individuals (Haskell et al., 2007). Adults who participate in greater amounts of aerobic activity above the recommendations are likely to further improve their health and reduce their risk of chronic disease and mortality (Haskell et al., 2007). These guidelines are based on multiple large-scale prospective observational studies that have supported a dose-response relationship between physical activity and risk of cardiovascular disease and premature death (Manson et al., 2002; Paffenbarger et al., 1993). However, recent research has shown that vigorous intensity activity may have a greater benefit for reducing cardiovascular disease and increasing longevity of life than moderate intensity activity (Lee et al., 1995; Swain et al., 2006). In a prospective cohort study of 17,321 middle-aged men, only vigorous intensity activity was associated with decreased mortality (Lee et al., 1995). Activity of a vigorous intensity creates a larger energy expenditure compared to activity of a moderate intensity that is performed for the same duration (Swain et al., 2006). The Harvard Alumni Health Study revealed that men who expended between 6300 and 12,600 kJ per week in vigorous exercise had a 0.75 to 0.87 times the risk of dying during 26 year follow-up period (Lee et al., 1995). In support, several epidemiologic studies found that when total energy expenditure was controlled

for, vigorous exercise provided greater cardioprotective benefits compared to moderate exercise (Swain et al., 2006). However, there is literature to suggest while vigorous activity may be needed to increase longevity, the health benefits of moderate intensity activity are similar to those of vigorous intensity activity.

Moderate intensity physical activity is the minimum threshold required to improve health and can have similar benefits to those observed with vigorous intensity exercise (Jakicic, 2003). A two year longitudinal intervention in previously sedentary men and women (N=235) compared a vigorous intensity fitness center-based program with a moderate intensity lifestyle intervention program. The results revealed that participants in both groups produced significant and comparable beneficial changes in physical activity level, cardiorespiratory fitness, blood pressure, and body fat percentage at month 24 compared to baseline (Dunn et al., 1999). A prospective study of 73,743 racially and ethnically diverse, postmenopausal women by Manson and colleagues (2002) found that both moderate intensity walking and vigorous intensity activity were associated with large reductions in incidence of cardiovascular events, irrespective of age, race, and body mass index (Manson et al., 2002). Women who either walked briskly or participated in vigorous exercise for a minimum of 150 minutes per week both reduced their risk by approximately 30% (Manson et al., 2002). Therefore, those individuals who prefer walking as their mode of activity or who cannot engage in activity of a vigorous intensity may utilize moderate intensity activity to accrue health benefits similar to those obtained through vigorous intensity activity.

Classifying Exercise Intensity

There are a variety of ways to classify the intensity of an activity; however, one of the most commonly used methods is the metabolic equivalent (MET). A MET is the physiologic theory used to express the energy expenditure of various physical activities as multiples of resting metabolic rate (Byrne et al., 2005). The definition of a MET is resting energy expenditure expressed either as 3.5 ml O₂/kg/min or as the ratio of work metabolic rate to standard resting metabolic rate of 1.0 kcal/kg/h (4.184 kJ/kg/h) (Ainsworth et al., 2000; Byrne et al., 2005). One MET is considered the resting metabolic rate achieved during quiet sitting (Ainsworth et al., 2000). The energy cost of an activity can be computed using the factorial system, by dividing the oxygen uptake of the activity (in ml/kg/min) by 3.5, or as multiples of resting energy expenditure (Jetté et al., 1990). Using METS is believed to be an advantageous method because it provides a common description of intensity across most modes of exercise (Balady, 2002). MET classifications of exercise intensity range from light exercise at 1-2.9 METS, moderate at 3-5.9 METS, and vigorous intensity at ≥ 6 METS (Pate et al., 1995). The MET factorial method is also commonly used to calculate the energy expenditure of an activity. This process involves classifying activities as multiples of resting metabolic rate (or multiples of 1 MET). In addition, a resource of various physical activities and their corresponding MET levels was developed to assist the coding of different physical activities and to support the comparison of activities between observational studies (Ainsworth et al., 2000). The Compendium does not account for individual differences in energy expenditure based on efficiency of movement and individual variations in energy expenditure can be great (Ainsworth et al., 1993). However, the MET system is

commonly used beyond the scope of its intended use in recommendations of physical activity levels.

The premise of MET levels is based on the assumption that the resting energy expenditure of the individual is equivalent to 3.5 ml O₂/kg/min. However, this measurement was determined based on the average resting VO₂ for one 70 kg, 40 year old man for which the original research is elusive (Wasserman et al., 1999). In addition, the use of the MET factorial method of classifying exercise intensity may not be accurate for all subject populations (Byrne et al., 2005; Wasserman et al., 1999). The factorial method may be inaccurate for estimating energy expenditure in people with different body mass and body fat percentage (Racette et al., 1995; Byrne et al., 2005). Research by Byrne and colleagues (2005) has shown that the standard 1 MET resting value of 3.5 ml O₂/kg/min overestimated the actual resting VO₂ of 769 subjects with an average BMI of 30 kg/m², by an average of 35%. Resting VO₂ was found to be significantly related to gender, age, BMI, body fat percentage, waist circumference, fat mass, and fat free mass, with body composition (fat mass and fat free mass) accounting for 62% of the variance. Body mass index (BMI), a commonly used measure to categorize weight status, was also strongly positively correlated with fat mass ($R^2 = 0.93$), and also explained the variance in resting VO₂ (Byrne et al., 2005). These same researchers also investigated the variability in the measured energy expenditure of walking at 5.6 km/h, a moderate intensity activity (3.8 METS), in a subset of 98 subjects of the study population. They found that the measured energy cost of walking at 5.6 km/h was an average of 22% greater than the predicted energy cost of the activity (4.6 ± 0.5 compared to 3.8 kcal/kg/h).

In a study of 14 obese women (body fat percentage >35%), Racette and colleagues (1995) noted that using the standard calculation of energy expenditure during physical activities of 13 obese women (body weight between 140% and 180% of the 1959 Metropolitan relative weight, and body fat >35%) could lead to overestimations of energy cost. The women participated in a study comparing doubly labeled water estimations of total daily energy expenditure against minute by minute heart rate monitoring and a 7 d physical activity recall questionnaire at the start and throughout a 12 wk weight reduction program (Racette et al., 1995). The researchers found that the use of multiples of basal resting metabolic rate (BMR) of 1 kcal/hr/kg of body weight was not an accurate estimate of physical activity energy expenditure of obese women. They attributed this overestimation to the lower metabolic activity of adipose tissue compared to lean tissue, which leads to an indirect proportional increase in BMR in relation to body weight (Racette et al., 1995).

Metabolic equivalents are also affected by comorbidities, which are likely to develop in overweight individuals, especially during the aging process (Peterson et al., 2004; Woolf-May & Ferrett, 2008). In a comparative study of 31 male post myocardial infarction (MI) patients and 19 male non-cardiac controls, Woolf-May and Ferrett (2008) compared MET values between the groups during the 10 m shuttle walking test (SWT). MET values for the post-MI group were observed to be significantly higher during speeds of 1.12-4.16 mph compared to the non-cardiac group. The non-cardiac group was able to complete a greater amount of shuttles (n = 56) compared to the cardiac group (n = 42), signifying a higher fitness level. While the groups did not differ in reported habitual physical activity, body mass, BMI, or age, it is possible that a difference in physical

fitness between the groups contributed to a portion of the higher MET levels in the post-MI group. In addition, it is also possible that an indirect effect of medication use in the post-MI group may have affected VO_2 (Woolf-May & Ferrett, 2008). Therefore, the use of MET multiples may be inaccurate in overweight and obese subjects, especially when these individuals suffer from more than just problems with weight status.

Physical Activity Recommendations

To promote and maintain health, and attenuate the risk of chronic disease and early mortality, healthy adults between 18 and 65 years old should engage in at least 30 minutes of moderate intensity physical activity on five days of the week or at least 20 minutes of vigorous intensity activity on three days per week (Haskell et al., 2007). The recommendation for moderate intensity activity can be met through an accumulation of several sessions of activity which last for a minimum of 10 minutes each (Haskell et al., 2007). However, this dose of physical activity may not be sufficient to induce weight loss in overweight individuals or to prevent weight regain in individuals who have lost a substantial amount of weight, more physical activity may be required for these individuals.

To prevent a weight gain of greater than 3% or to induce modest weight loss, healthy persons between the ages of 18 and 65 years should engage in a minimum of 150-250 minutes per week of moderate intensity physical activity (Donnelly et al., 2009). This dose of physical activity should result in an energy expenditure of ~1200 to 2000 kcal per week (Donnelly et al., 2009). Accumulation of greater amounts of physical activity above 250 minutes per week is associated with clinically significant weight loss and improved weight maintenance (Donnelly et al., 2009). This dose-response relationship corresponds

to an energy expenditure of greater than 2000 kcal per week (Donnelly et al., 2009). For overweight individuals, the accumulation of exercise duration in intermittent bouts lasting longer than 10 minutes

Methods of Measuring Physical Activity

There are many different tools that research studies utilize to measure subjects' physical activity levels. Each tool has advantages and disadvantages when compared to the other methods. Methods of measuring physical activity can be subjective, including self-report by the subjects, and objective, including pedometers, heart rate monitoring, indirect calorimetry, and accelerometry. The lack of consistency in measurement methods between research studies makes health outcomes hard to quantify. A summary of each method is presented below.

Self-Report

Self-report of physical activity levels by subjects includes handwritten or electronic daily diaries and activity recall questionnaires. Subjects account for duration, type, and intensity of activity during the time period designated by the researchers. There are several advantages to using the self-report method. Self-report is a practical method because of their ease of administration and distribution with a wide range of subject populations (Tudor-Locke & Myers, 2001). Self-report and questionnaires involve minimal subject time and require less subject effort compared to other methods, and it is relatively easy for the researchers to calculate results (Racette et al., 1995). Validation studies have also been completed to support the accuracy of using specific questionnaires to calculate daily energy expenditure in obese subjects (Racette et al., 1995). However, self-report techniques depend on the individual's willingness to accurately recall and

record daily activity (Reiser & Schlenk, 2009). Self-report measures also usually do not capture the accomplishment of lower intensity activities, which are characteristic of sedentary populations (Tudor-Locke & Myers, 2001). Subjects also may have trouble comprehending questions about intensity of activity, whether relative to their own pace, or in absolute terms (Tudor-Locke & Myers, 2001). In addition, no singular self-report tool exists for all populations or purposes, making the choice of instrument important (Tudor-Locke & Myers, 2001). Therefore, the use of an objective measurement may be preferable when attempting to assess energy expenditure.

Pedometers

Pedometers, or step counters, are small devices worn on the body which count the number of steps the individual takes. Pedometers measure steps taken by the motion of either a spring or a lever within the device (Reiser & Schlenk, 2009). They are an objective measurement of physical activity because the subject is only required to report the number of steps on the device output at the end of a certain period of time. There is a wide range of pedometers available for use, and devices vary in cost and accuracy. Pedometers are relatively inexpensive and data management requires no additional instrumentation (Reiser & Schlenk, 2009). However, these devices have limited memory and data storage capabilities. Pedometers are sensitive enough to capture the small individual differences in patterns of irregular or inconsistent physical activity, but the accuracy of step counting can be affected by several factors (Reiser & Schlenk, 2009; Tudor-Locke & Myers, 2001). Pedometer output can be affected by walking speed, alterations in gait, restriction by clothing and excessive adiposity, and poor placement on the body (Melanson et al., 2004; Reiser & Schlenk, 2009). In a study of 250 male and

female subjects of varying age (19-85 yr) and body mass index (17.9-43.7 kg/m²), pedometer accuracy was 60-70% at the slowest subject-selected walking speeds, but >96% at subject-selected faster walking speeds (≥ 3.0 mph) (Melanson et al., 2004). Self-selected walking speed was seen to significantly decrease with increases in BMI from the normal weight (<25 kg/m²) to obese (>30 kg/m²) category. While BMI was not a significant predictor when predicting the difference between counted and measured steps in this study, if overweight or obese individuals ambulate at slower speeds, the accuracy of pedometers may be reduced (Melanson et al., 2004).

Heart Rate Monitors

Monitoring heart rate over time may be used as an indirect measurement to estimate energy expenditure because there is a linear relationship between heart rate and energy expenditure (Garet et al., 2005). In a study of 61 adults with an average BMI of 26.7 ± 6 kg/m², a moderate relationship was observed between heart rate and oxygen uptake (VO₂) over a range of moderate intensity field and laboratory activities, $r = 0.68$ (Strath et al., 2000). Thus, heart rate was found to be a moderate indicator of energy expenditure. Heart rate monitoring is an advantageous method of assessing energy expenditure because it is practical, affordable, and non-invasive tool to monitor levels of physical activity. There are also several different methods of estimating energy expenditure from heart rate data: using average pulse rate, net heart rate (activity heart rate – resting heart rate), and single or multiple individual HR-VO₂ calibration curves (Garet et al., 2005). However, heart rate is affected by several factors which may influence its accuracy when estimating energy expenditure from equations, such as medications, pathology, stress level, training status, and age (Reiser & Schlenk, 2009).

For individuals with differing levels of adiposity and training status, the heart rate method is most accurate when individualized calibrations of the relationship between heart rate and VO_2 at a range of activities intensities are used (Racette et al., 1995). In addition, when obese individuals are attempting to lose weight, and thus alter daily energy expenditure, the heart rate method may not be sensitive enough to detect the changes in energy expenditure which accompany weight loss (Racette et al., 1995).

Indirect Calorimetry

Indirect calorimetry measures the oxygen uptake and carbon dioxide output of an individual to estimate energy expenditure. This technique assumes that all oxygen used by the body is to breakdown fuel sources for use, and that all carbon dioxide produced in the breakdown is measured (Perseghen, 2001). The subject must perform activities while breathing into a facemask or through a mouthpiece while wearing a nose clip. A metabolic system simultaneously collects and analyzes the individual's expired air for levels of oxygen and carbon dioxide, and calculates VO_2 , or energy expenditure. The use of indirect calorimetry is advantageous when attempting to measure physical activity levels because it is a highly accurate method. The error with indirect calorimetry is approximately 2-3% (LaPorte et al., 1985). However, there are several disadvantages to using indirect calorimetry, which limit its usefulness in large-scale studies of physical activity levels. The equipment involved with indirect calorimetry is very expensive and also requires a large amount of time to manage the data. This technique also requires a high degree of cooperation from the subject. Performing various activities while wearing the mouthpiece or facemask used in indirect calorimetry is sometimes not well tolerated

by the subject, limiting the duration of data collection. Therefore, a tool which is as accurate, but which requires less time and effort from the subject is needed.

Accelerometers

Accelerometers are small, compact devices that can monitor frequency, intensity, and duration of activity by the wearer by measuring acceleration forces, or ‘g’ forces. Accelerometers accomplish this by recording electrical changes obtained from the distortion of piezoelectric ceramics held within the apparatus (Meijer et al., 1991). Acceleration is the change in speed with respect to time, and its measurement more accurately reflects the intensity of the activity performed (Reiser & Schlenk, 2009). Movement is recorded using the piezoelectric ceramics and a microprocessor held within the casing of the instrument (Reiser & Schlenk, 2009). Accelerometers not only record step counts, but some also record movement (acceleration) in up to three different dimensions. The number and alignment of the piezoelectric ceramics dictates whether the device measures movement in one (uniaxial) or three (triaxial) planes (Tudor-Locke & Myers, 2001). Accelerometers can record data in various pre-determined lengths of time, or epochs, as desired by the programming researcher. Accelerometers are small in size, lightweight, and are less intrusive than other methods of physical activity assessment.

Accelerometers are a more accurate method of assessing physical activity than pedometers, but are much more expensive to employ than pedometers. These devices are advantageous for use during physical activity assessment because they are objective and do not suffer from arbitrary and methodical error caused by respondents and interviewers. Accelerometry allows for real time data collection to provide feedback on the physical activity patterns of the subject wearing it (Matthews, 2005). However, this method is not

perfect and there are drawbacks to utilizing accelerometry to assess physical activity. Accelerometer output is altered by the site of attachment on the body and areas of the body are differentially active depending on the exercise (Westterterp, 1999). Most studies utilize an accelerometer attached to the hip, waist, or low back and are not sensitive to weight independent activities such as cycling, weight training, and swimming (Westterterp, 1999). Data management is time intensive and some accelerometers require technical proficiency and a computer to download accelerometer output (Tudor-Locke & Myers, 2001). Accelerometers are more sensitive to light intensity activities than pedometers, and are less susceptible to artifact in the data output caused by vibrations unrelated to activity than pedometers (Reiser & Schlenk, 2009).

The accelerometer records data as ‘activity counts,’ which are the product of the individual’s frequency and intensity of motion. From these activity counts, total energy expenditure can be determined, based on the characteristics of the individual like age, gender, height, and body mass (Tudor-Locke & Myers, 2001). However, one of the greatest drawbacks of accelerometer use is that there is no single adjustment coefficient between devices (Tudor-Locke & Myers, 2001). Most major types of accelerometers have their own regression equations to estimate the individual’s energy expenditure, but the various equations can lead to differences in calculated energy expenditure (Reiser & Schlenk, 2009).

Accelerometers are widely used in physical activity research and there are a variety of different manufacturers of the devices and, in general, no device is superior to another device (Rothney et al., 2008). The choice of accelerometer manufacturer to utilize depends on the research question involved, as mechanical characteristics of

monitors change between devices. A uniaxial accelerometer measures acceleration in the vertical plane, in contrast, the biaxial and triaxial devices are sensitive to motion in two and three dimensions, respectively (King et al., 2004). These differences contribute to differences in accelerometer output, which prohibits interchangeability between devices. There are currently several commercially available accelerometers for use which are also commonly used in physical activity literature. The ActiGraph (ActiGraph, Fort Walton, FL, formerly Computer Science Applications), is primarily sensitive to movement in the vertical plane and can collect data in 5 s to 1 min epochs. The RT3 (StayHealthy Inc., Monrovia, CA) is a triaxial accelerometer measuring three-dimensional piezoelectric signals and can assess data between 1 s and 1 min intervals. The BioTrainer (IM Systems, Baltimore, MD) is a biaxial device that can sample data in epochs from 15 s to 5 min. The Actical (Respironics Inc., Murrysville, PA) is an omnidirectional accelerometer that can measure acceleration in multiple planes and can store data in epochs as short as 15 s.

Reliability and Validity of Accelerometry

The validation of techniques of estimating physical activity levels and energy expenditure is required in order for the method to be used in research studies. A considerable amount of research has been done to assess the validity of accelerometers used today and has generally been strong in laboratory studies (Freedson et al., 1998; Nichols et al., 1999; Welk et al., 2003; Westerp, 2000). Accelerometers have been observed to be less precise when estimating energy expenditure in the field (Hendelman et al., 2000; Welk, 2000). In an attempt to evaluate the validity of accelerometry against indirect calorimetry, the CSA, Tritrac, and Biotrainer monitors were worn simultaneously for comparison (Welk et al., 2000). Fifty two adults with an average BMI of 23 kg/m²

completed six different activities (including lifestyle activities) of six minutes in duration, with every subject completing treadmill walking at 3 mph, 4 mph, and jogging at 6 mph. Strong correlations were observed between monitors and measured energy expenditure (range: $r = 0.85-0.92$) for the treadmill activity. The CSA predictions of energy expenditure were not significantly different from the measured values from indirect calorimetry at any treadmill speed. However, the Biotrainer and Tritrac tended to overestimate energy expenditure at every speed, with overestimations reaching 128% and 112%, respectively. Smaller correlations were observed for the relationship between accelerometry and lifestyle activity (range: $r = 0.40-0.47$). All three monitors tended to underestimate energy expenditure, compared to indirect calorimetry when activities were completed in the field. The average underprediction of all six activities ranged from 38-48%, but differed between activities. Underprediction of field activities could be explained by the inability of hip worn accelerometers to capture upper body motion, but is included in many lifestyle activities (Welk et al., 2000). Strong correlations were observed among the three different monitors for the laboratory activities ($r = 0.84$) and for the lifestyle activities ($r = 0.82$).

The validity of the Actical accelerometer has been evaluated in a few studies using adult subjects (Heil, 2006; Rothney et al., 2008; Welk et al., 2004). Heil (2006) developed algorithms for predicting activity energy expenditure in 24 adults (BMI range of 20.5-30.1 kg/m²). Participants wore Actical devices on the ankle, wrist, and hip and carried a portable metabolic system in a backpack while performing 10 activities: supine rest, three sitting activities, three house cleaning activities, and treadmill walking and jogging. Predictions of activity energy expenditure from the algorithm derived from the

accelerometer worn on the hip were not statistically different from measured energy expenditure values. However, there was a considerable amount of variation in the regression equations when predicting energy expenditure ($r^2 = 0.14-0.85$).

In a second calibration study, two published regression equations developed using lifestyle activities were evaluated for their accuracy in predicting energy expenditure compared to measured energy expenditure by a room calorimeter (Rothney et al., 2008). Eighty five adults with a range of BMIs from 16.9-42.1 kg/m² completed an overnight stay in a room calorimeter while wearing three accelerometers, including the Actical. Subjects completed 10 minute sessions of prescribed activities in the morning (self-paced walking and jogging) and in the afternoon (sedentary activities) with 10 minutes of rest in between sessions. Between periods of activity the subjects were instructed to employ their regular activities of daily living. The prediction of physical activity levels by the regression equations utilized by the Actical was significantly different from measured energy expenditure by the room calorimeter. The equations also underestimated the time spent in sedentary physical activity and over predicted the time spent in light intensity physical activity (Rothney et al., 2008).

A subsequent study revealed similar results for the ability of the Actical to predict energy expenditure (Crouter & Bassett, 2008). Forty eight subjects (BMI range 17.9-40.6 kg/m²) completed 10 minutes of a variety of lifestyle activities from walking around a track to washing dishes while wearing a portable indirect calorimeter. The regression equation developed by the researchers lead the Actical to provide a closer estimate of time spent in light, moderate, and vigorous intensity activity as measured by standard MET levels. Significant, yet moderate, agreement was observed between the regression

equation and measurement by indirect calorimetry (Kappa Statistic = 0.531, SE = 0.222). In summary, accelerometry is a valid method of assessing physical activity, but the strength of validity varies between activities completed (laboratory vs. field setting). The prediction of energy expenditure varies slightly between monitors, but each device provides similar information.

Reliability testing among accelerometers is a new field of testing, but is important because it sets the boundaries for validity (Welk et al., 2004). Most commonly reliability testing employs a set-up of accelerometers on a platform device that is set to a standardized amount of motion. Less common is testing which utilizes free-living activities in a standardized protocol. Welk and colleagues (2004) compared the reliability of four accelerometers, the CSA (now ActiGraph), Biotrainer, Actical, and Tritrac R3D in a free-living physical activity situation. Four different groups of college-aged adults, average BMI for all groups 23.84 ± 3.83 kg/m², wore a different accelerometer to assess the reliability of the monitors over multiple trials and to examine intra-individual variability. Each subject completed three trials of treadmill walking at 3 mph while exclusively wearing one of the four monitors on the right hip. Each trail was 5 minutes long and was separated by 1 minute of standing rest during which time the researchers switched units within the same manufacturer. The final analysis included data from ten ActiGraphs, nine Biotrainers, nine Tritrac R3Ds, and seven Acticals. The variability between multiple units of the same accelerometer was assessed by coefficients of variation (CV). The CV values were comparable between the ActiGraph, Tritrac, and Biotrainer, with mean CV values of the three trials of 8.9, 9.4, and 10.0%, respectively. The mean CV for the Actical was higher, at 20.0%. Generalizability (G) was also

calculated to represent the total variability related to the accelerometer data. The generalizability for a single trial with a single monitor was highest for the Actigraph ($G = 0.64$), Tritrac ($G = 0.573$), Biotrainer ($G = 0.557$), and lowest for the Actical ($G = 0.432$). The Actigraph was concluded to have acceptable reliability, but the other devices needed more research to improve the reliability for different research applications (Welk et al., 2004).

Review of Calibration Studies

Raw accelerometer output, or activity counts, is generally not useful in answering most research questions. Therefore, the conversion of counts to other measures which are important to assessing physical activity levels is important. Counts are typically converted to energy expenditure and/or time spent in light, moderate, and vigorous intensity activity. This process of conversion is called calibration. Calibration of an accelerometer is completed by comparing activity counts to a known standard, usually a direct measure of metabolism, to determine the intensity represented by the activity counts (Ward et al., 2005). Early calibration research focused on activities which took place in a controlled laboratory setting to evaluate the relationship between activity counts and measured metabolic data measured by indirect calorimetry (Welk, 2005). Recent research has shifted towards observing activities in the field setting which represent more free-living activities using either indirect calorimetry or doubly labeled water as measured metabolic data. Researchers then compute a linear regression equation, either for the group to describe their physical activity or a regression equation for each individual subject. The equation resulting from calibration studies is then used to predict energy expenditure or to provide activity count cut-point levels to quantify

activity intensity (Ward et al., 2005). The variations of mechanics of different accelerometers require separate calibration studies for each monitor available for use. In addition, calibration equations should be developed using data from a sample that is representative of the population of interest (Welk, 2005). Therefore, when a new accelerometer is manufactured, or a new population is studied using an existing accelerometer, a calibration study must be performed.

Laboratory calibration studies frequently utilize progressive treadmill protocols because walking is one of the most commonly employed modes of activity by individuals and research protocols. The criterion measure usually employed to record actual energy expenditure during laboratory studies is indirect calorimetry using a metabolic system. Energy expenditure is then calculated from activity counts, most commonly using multiple regression analysis. There has been little calibration research completed using only overweight and obese adults. A calibration study of 26 overweight or obese older adults (average BMI of 30.17 ± 5.01 kg/m²) with diagnosed type 2 diabetes mellitus exists using the ActiGraph accelerometer (Lopes et al., 2009). These older adults (average age = 62.6 years) completed the following sequence of physical activities while VO₂ was recorded by a metabolic unit: rest, seated, standing, walking at 2.5, 5, and 6 km/hr. Receiver Operating Characteristic (ROC) curve analysis was used to determine the thresholds for light, moderate, and vigorous intensity as defined by standard MET multiples. The cut-point for light intensity exercise was 200 counts per minute (CPM), 1240 CPM for moderate, and 2400 CPM for vigorous exercise.

Various other laboratory calibration studies exist who employ healthy, normal weight adults. Freedson and colleagues (1998) completed a calibration study using the

Computer Science and Applications (CSA), now known as the ActiGraph, accelerometer on the right hip. Fifty adults (25 males, 25 females, average BMI = 22.8 kg/m²) completed six minutes of steady state exercise at three different speeds on a treadmill: slow walking (4.8 km/h), fast walking (6.4 km/h), and jogging (9.7 km/h) while simultaneously recording metabolic data through indirect calorimetry. Five minutes of rest separated various stages of the protocol. The cut-points developed were in reference to the standard MET category levels commonly used in the literature (light <2.9 METS, moderate 3.0-5.9 METS, vigorous 6.0-8.9 METS, and very vigorous >9.0 METS). Linear regression was run to calculate activity counts at the desired MET level which corresponded to light (<1952), moderate (1952-5724), vigorous (5725-9498), and very vigorous (>9498).

Cut-points have also been established using the RT3 accelerometer (StayHealthy, Inc., Monrovia, CA). Fifteen men with an average BMI of 22.5 kg/m² completed a variety of activities to determine cut-point values for moderate and vigorous intensity exercise (Rowlands et al., 2004). The criterion measurement for energy expenditure was indirect calorimetry. All subjects completed four minutes of treadmill exercise at 4, 6, 8, and 10 km/h, hopscotch, and kicking a ball; additionally, subjects sat quietly for 10 minutes. The same RT3 accelerometer was worn on the right hip for all participants. Cut-point values for the treadmill activities alone were 1317 counts for moderate (3 METS) and 2637 counts for vigorous (6 METS). While several studies established the validity of the BioTrainer accelerometer, neither study presented cut-point values for moderate or vigorous intensity exercise (King et al., 2004; Welk et al., 2003).

Field based research attempt to bridge the gap between tightly controlled laboratory exercise and exercise that individuals complete in free-living conditions. The choice of criterion measure used to measure energy expenditure in field based research is different. Self-report is an easy to administer tool, but is not the most accurate at capturing true energy expenditure (Welk, 2005). Researchers have the doubly labeled water technique and portable metabolic systems to choose from, but both are costly and time intensive for data management. Hendelman and colleagues (2000) completed a calibration study of moderate intensity exercises in the field. Twenty five adults (10 male, 15 female) with an average BMI of 24.4 kg/m² completed three activity sessions wearing both the ActiGraph and the Tritrac accelerometers. Energy expenditure was measured using a portable metabolic system worn on the lower back. All subjects completed a session on an indoor track walking at self-selected leisurely, comfortable, moderate, and brisk paces for five minutes at a time. Five minutes separated each bout. Subjects also played two holes of golf, using a pull cart to move their clubs. During the final session, subjects completed window washing, dusting, vacuuming, lawn mowing, and gardening. Cut-points were developed for each accelerometer using regression analysis and separated by the activities performed, either from the walking-only trial, or all activities collapsed together. For the walking-only trial the cut-points for the ActiGraph were 2192 and 6893 and for the Tritrac, 1028 and 2633, for moderate and vigorous intensity, respectively. For all the activities combined, the cut-points for the ActiGraph were 191 and 7526 and for the Tritrac, 167 and 2904, for moderate and vigorous intensity, respectively. This study revealed huge differences in activity counts between

accelerometers when assessing the same workload and when different activities are used in calibration research; specific calibration analyses are needed for individual devices.

In another field based study, 70 adults with an average BMI of $26 \pm 5.4 \text{ kg/m}^2$ completed one to six activities in one or more of the following categories: yard work, occupation, housework, family care, conditioning, and recreation (Swartz et al., 2000). Each activity was performed for 15 minutes and between activities a five minute rest period was employed in an attempt to ensure energy expenditure was representative of the activity that was presently being performed. Each participant wore two CSA (Actigraph) accelerometers, one on the right hip and one on the dominant wrist. Energy expenditure was measured using the portable Cosmed K4b² indirect calorimetry system. Cut-points were determined after collapsing all activities together and were from the hip accelerometer. Moderate intensity (3 METS) corresponded to 574 counts, vigorous intensity (6 METS) corresponded to 4945 counts, and very vigorous intensity corresponded with 9317 counts. These cut-points are different from the cut-points presented in by Hendelman and others (2000) at both moderate and vigorous intensity activity when both laboratory and free-living activities are considered.

Actical Accelerometer

The Actical accelerometer (Respironics Inc., Murrysville, PA) is becoming a more widely employed device in objective measuring of physical activity (Crouter & Bassett, 2008). The Actical is an “omni-directional” accelerometer; it is able to record movement in all directions. The device is waterproof, small (28 x 27 x 10 mm) and lightweight (17 g) and can measure accelerations in the range of 0.05-2.0 G. It is sensitive to motion in the range of 0.35-3.5 Hz. The Actical can record data in epochs from

seconds to minutes and can store up to 44 days of data. The device downloads the data it stores to a computer using a telemetry-based receiver that is connected to the computer. The activity counts produced by the Actical are proportional to the magnitude and duration of the recorded accelerations and are equivalent to the energy expenditure of physical activity (Heil, 2006). Due to the fact that the use of the Actical is becoming more widespread in the literature, calibration studies are required to assess the validity of the monitor and to convert its data into a reliable measurement of physical activity.

Several Actical calibration studies using children have presented thresholds for activity intensity (Pfeiffer et al., 2006; Puyau et al., 2004). Thirty two children aged 7-18 yr (BMI range: 13.7-35.7 kg/m²) completed a resting metabolic rate measurement, Nintendo game session, computer work, cleaning, ball toss, aerobics, and treadmill walking in a room calorimeter (Puyau et al., 2004). Thresholds were developed using the following definition: sedentary activity was defined as an activity energy expenditure (AEE) < 0.01 kcal/kg/min, light intensity as $0.01 \leq \text{AEE} < 0.04$ kcal/kg/min, moderate intensity as $0.04 \leq \text{AEE} < 0.10$ kcal/kg/min, and vigorous intensity as $\text{AEE} \geq 0.10$ kcal/kg/min. Actical activity count thresholds were presented for light intensity (100 counts), moderate intensity (1500 counts), and vigorous intensity (6500 counts). Activity count thresholds have also been developed in preschool age children (Pfeiffer et al., 2006). Eighteen preschool children aged 3-5 years old wore an Actical accelerometer and a portable indirect calorimeter during the study. All children completed a resting measurement, five minutes of level ground walking and jogging at 2, 3, and 4 mph with rest in between speeds, and 20 minutes of unstructured activity in an indoor and outdoor playground setting. Standard MET definitions were not used to determine count cut-off

points because they may not be applicable to young children (Pfeiffer et al., 2006).

Measured VO_2 values were utilized as definitions of moderate ($\text{VO}_2 = 20 \text{ ml/kg/min}$) and vigorous ($\text{VO}_2 = 30 \text{ ml/kg/min}$) intensity activity in these subjects. The threshold for moderate intensity activity was 2860 counts/min and 5644 count/min for vigorous intensity activity.

While several studies have presented cut-points in children, cut-points in adults remain elusive. One study presented Actical thresholds in sedentary, obese adult males (average BMI = $35.4 \pm 4.4 \text{ kg/m}$) who were classified as high risk for suffering a cardiac event (Holleman et al., 2008). All over-ground walking sessions (field based) lasting at least 10 minutes were analyzed and Receiver Operating Characteristic (ROC) curve analysis was run on speeds of 2, 2.5, and 3 mph. All sessions were stated to represent moderate intensity activity, and no criterion measure was collected to validate energy expenditure. The average activity count at 2 mph was 1750 CPM, 2250 CPM at 2.5 mph, and 2750 CPM at 3 mph. The validity of the Actical has been evaluated in a few studies using adult subjects described in the literature review of this paper (Heil, 2006; Rothney et al., 2008; Welk et al., 2004). No activity count cut-points for intensity thresholds were presented in any of these studies, but a cut-off of 5700 counts per minute was proposed to differentiate walking from running in adults (Crouter & Bassett, 2008).

One study has presented cut-points for activity intensity in adults using the Actical accelerometer (Diaz, 2009). In unpublished work, 25 adults with an average BMI of $23.5 \pm 3.5 \text{ kg/m}^2$ completed a laboratory calibration of the Actical accelerometer. All subjects wore the Actical and energy expenditure was measured by indirect calorimetry. Subjects completed a level treadmill protocol of four minute stages, beginning at 2 mph

and increasing 1 mph at the end of every four minutes. The test was terminated when the subject reached 75% of their individual heart rate reserve. Separate linear regression equations were calculated for each subject and using the standard MET definitions of exercise intensity, the cut-point for moderate intensity was an average of 1782 counts/minute and an average of 6464 counts/minute for vigorous intensity exercise. In this study, activity count thresholds were also calculated using percentages of VO_2 as the definition of activity intensity because of the controversy surrounding the use of METS (see Classifying exercise intensity section). Percentages of the subject's maximum oxygen consumption ($\text{VO}_{2\text{max}}$) were used as the definitions of moderate (40% $\text{VO}_{2\text{max}}$) and vigorous (65% $\text{VO}_{2\text{max}}$) intensity exercise, with corresponding activity count thresholds of 4952 and 9714, respectively. However, a major limitation of this study was that resting measurements of VO_2 were elevated and may have lead to inaccurate calculations of percent $\text{VO}_{2\text{max}}$.

Summary

The benefits of physical activity are great for the individual's health. However, most adults are not meeting the recommended amount of physical activity to attain these benefits. Individuals may participate in moderate or vigorous intensity exercise, or a combination of both, to reach the guidelines of activity. It is therefore important to be able to quantify the amount of physical activity of a person or group, especially in the research setting. There are many tools to choose from to measure physical activity, including self-report, pedometers, heart rate monitors, indirect calorimetry, and accelerometers. The use of accelerometers has recently increased in the research literature, with many different devices available for commercial use. Monitors, and

subsequently their output, are not completely interchangeable due to differences in manufacturing, sensitivity, and calibration equations. Calibration equations also must be developed from sample data which is representative of the population of interest because differences in height, weight, body composition, economy and movement patterns all have the potential to influence output (Welk et al., 2005). Therefore, it is important for accelerometer output to be specific to the accelerometer and the population it is used in. The purpose of this study was to determine activity counts per minute thresholds of activity intensity using the Actical accelerometer in overweight and obese adults.

Chapter III

METHODOLOGY

The purpose of this study was to compute Actical cut-points for moderate and vigorous intensity exercise in overweight and obese adults. All subjects completed one progressive submaximal exercise session. Oxygen uptake was measured using indirect calorimetry as the criterion measure. The data from the current study was compared to previously collected data from this laboratory using the same methodology in normal weight adults. All data were collected in the Applied Physiology Laboratory on the campus of the University of North Carolina at Chapel Hill and in the school gymnasium at Haw River Elementary School located in Burlington, North Carolina.

Subjects

Thirty overweight or obese ($\text{BMI} > 25 \text{ kg/m}^2$) male and female adults aged 18 to 50 years were tested in this study. In addition, one normal weight ($\text{BMI} < 25 \text{ kg/m}^2$) female was tested in an attempt to balance sample size between groups. Participants were obtained through the ongoing UNC Family Partners for Health study (Principal Investigator: Diane Berry, grant number 1RO1NRO10254-03) and from the Chapel Hill, NC area. Each potential subject was informed of the possible risks of the exercise protocol and signed an informed consent, previously approved by the UNC Institutional Review Board, before they participated in this study. All subjects had received medical clearance to participate in physical activity from a UNC Family Partners for Health study

related nurse, or their personal physician. Subjects were required to have the ability to walk and jog on a motorized treadmill to be included in this study. Those individuals with a musculoskeletal injury, uncontrolled high blood pressure or diabetes, history of myocardial infarction, who were claustrophobic, or were pregnant were excluded from participating.

Instrumentation

The subjects' characteristics were measured using a portable stadiometer (Seca, Hamburg, Germany) for height and an electronic scale (Tanita, Arlington Heights, IL) for body mass when exercise took place at Haw River Elementary School. When exercise took place in the Applied Physiology Laboratory, height was measured using a portable stadiometer (Perspectives Enterprises, Portage, MI) and a mechanical scale (Detecto, Webb City, MO) for body mass. Body mass index (kg/m^2) was calculated from measured height (m) and mass (kg) obtained before their participation in the exercise protocol. Heart rate was measured using a Polar heart rate monitor (Polar Electro, Inc., Lake Success, NY) and rating of perceived exertion (RPE) was measured using Borg's original 6-20 RPE scale (Borg, 1970).

Activity counts during subjects' treadmill exercise were measured by the Actical accelerometer (Respironics Inc., Bend, OR). The Actical accelerometer is a small (28 x 27 x 10 cm), lightweight (17 g) device which measures accelerations in multiple planes (Crouter & Bassett, 2008). The Actical was initialized to measure activity counts in one minute epochs. Activity count data was uploaded using the Actical reader and Actical software version 2.0 (Respironics, Inc., Bend, OR). Breath by breath pulmonary gases collected were analyzed by the K4b² portable metabolic system (COSMED, Rome, Italy)

during testing in the field and by the Parvo Medics TrueMax 2400 Metabolic Measurement System (Parvo Medics, Salt Lake City, UT) during testing in the laboratory. The use of the COSMED K4b² system for measuring oxygen uptake over a range of exercise intensities during cycling has been validated (McLaughlin et al., 2001). Although the K4b² system measured VO₂ significantly higher than the Douglas bag method between power outputs of 50-200 W, differences were < 100 ml/min (McLaughlin et al., 2001). Measurements of VCO₂ with the K4b² were significantly different only at 200 and 250 W (McLaughlin et al., 2001). An attempt was made during this study to ensure that the COSMED and Parvo Medics metabolic systems measured oxygen uptake consistently. Standard gases (16% O₂, 4% CO₂) and ventilatory volumes (1L) were used to compare VO₂ measurements between the two instruments. It was found that the COSMED measured VO₂ 0.3% higher than the Parvo Medics metabolic system, which was deemed an acceptable error rate; therefore, both instruments were used for data collection in this study.

All exercise took place on a calibrated motorized treadmill in either the gymnasium of Haw River Elementary School in Burlington, North Carolina (Marquette, United States) or on a Quinton treadmill in the Applied Physiology Laboratory on the campus of the University of North Carolina- Chapel Hill (Cardiac Science Corporation, Bothell, WA). Both treadmills were calibrated for the range of speeds used in the exercise protocol according to manufacturer's directions (Table 1).

Protocol

Subjects were asked to complete only one exercise session which lasted approximately 45 min. Informed consent was obtained from all subjects before testing

began. All study exercise sessions took place at the same time of day (during the late afternoon to evening), regardless of field or laboratory location. Subjects received prior approval from their personal physician to participate in physical activity or were screened upon arrival to the Applied Physiology Laboratory to ensure they were ready to participate in physical activity.

Before subjects arrived to the exercise session, the Actical accelerometer was initialized with the subject's information and the COSMED or Parvo Medics system was calibrated using standard gases. Upon arrival, height and body mass of subjects were measured. Subjects were fitted with the heart rate monitor and asked to rest seated for five minutes in order to obtain an accurate resting heart rate value. After the rest period was completed, the Robergs and Landwehr (2002) equation [$208.754 - (0.734 * \text{age})$] was used to calculate predicted maximal heart rate of the participant. Heart rate reserve was then calculated using the Karvonen formula (Karvonen et al., 1957). The termination point of the exercise session was 75% of the subject's heart rate reserve. Subjects then had the opportunity to familiarize themselves with the motorized treadmill and ask any questions they had of the researcher. They then learned how to report ratings of perceived exertion using the Borg scale. Next, subjects were fitted with the Actical accelerometer on the right hip aligned with the midline of the right thigh. The portable COSMED system was then strapped to the subject's back or the subject was then fitted with the mouthpiece, depending on the location of testing. All COSMED straps were adjusted so the pack containing the COSMED system was fitted snug against the subject, with all wires held in place, but remained comfortable. The COSMED headpiece containing the

mouthpiece for the subject to breathe into was the fitted and adjusted to ensure no air leaks occurred.

The subject then moved to the treadmill and was asked to stand still for a two minute recording of resting oxygen uptake. The exercise protocol (Table 1) involved walking, and possibly jogging, for four minute stages at a constant (0% grade), with speed increasing 1.0 mile per hour (mph) at the end of every four minute stage. The test terminated when 75% of heart rate reserve was reached. Heart rate and RPE were monitored throughout the test, with recordings of each taken during the last 10 s of each stage. When the subject reached the termination heart rate value, the test was ended, and final heart rate and RPE rating were recorded. If the subject reached this heart rate value during the first minute of the stage, the subject was encouraged to continue exercising until minute two, producing only two minutes of data for that stage. If the subject reached this heart rate value in the second or third minute, the researchers encouraged the subject to continue and complete the end of the stage, producing four minutes of data. The subject had the option to end the test at any point during the protocol.

Table 1. Exercise session protocol, constant grade (0%).

Stage (4 min)	Treadmill Speed (mph)
1	2.0
2	3.0
3	4.0
4	5.0
5	6.0

Subjects engaged in an active walking cool down at 2.0 mph until their heart rate slowed to at least 120 beats per minute (bpm). When subjects' heart rates sufficiently slowed, they were helped off the treadmill and encouraged to drink water and lightly

stretch to avoid any possible post-exercise muscular pain. Subjects then sat in a chair until their heart rate returned to resting values while the researcher went over their heart rate response to the session with them. Subjects who desired were provided with a personalized exercise plan based on their heart rate training zones. At this point, subjects rejoined the Family Partners for Health exercise class or were released from the APL.

Data Management

Oxygen uptake (VO_2) data from minutes one and two of each stage were eliminated in order to obtain an accurate representation of steady state exercise at that speed. The average of the oxygen uptake of minutes three and four were used to represent steady state metabolic demands of that stage. For subjects who did not complete the final stage of the protocol, the last minute of data was used. To reduce activity count data, minutes one and four of each stage were eliminated in order to remove any changes in acceleration due to changes in treadmill speed between stages. The average of minutes two and three were used to represent the counts for the stage. For subjects who did not complete four minutes of the final stage, the average of the last two minutes was used. However, for those subjects who had a wide variation in the last two minutes of data, the first of the final two minutes was used to represent the speed.

Individual regression equations were computed for each subject to determine activity counts at 3 ($\text{VO}_2 = 14 \text{ ml/kg/min}$) and 6 METS ($\text{VO}_2 = 24.5 \text{ ml/kg/min}$) (Pate et al., 1995). The association between activity counts and exercise intensity was calculated using METs as the measure of intensity. All VO_2 used in calculations were verified for the attainment of steady state responses. To determine the association between activity counts and VO_2 for each individual subject, maximum oxygen uptake ($\text{VO}_{2\text{max}}$) was first

estimated for each subject (Margaria et al., 1965). This procedure has been validated for use in various subject populations with an established variability of $\pm 7\%$ (Margaria et al., 1965). Relative VO_2 at two different workloads (speeds) was used to predict $\text{VO}_{2\text{max}}$ for each individual subject. Only speeds during which the subject completed all four minutes were used in the calculation. Therefore, all subjects used 2.0 mph as the low workload and their highest speed during which four minutes were completed as the high workload. The following prediction equation was then used: $\text{VO}_{2\text{max}} = [\text{HR}_{\text{max}} * (\text{VO}_2'' - \text{VO}_2') + \text{HR}''\text{VO}_2' - \text{HR}'\text{VO}_2''] / [\text{HR}'' - \text{HR}']$ where HR_{max} represented predicted maximum heart rate, VO_2'' represented the oxygen uptake at the high speed, VO_2' the oxygen uptake at the low speed, HR'' the heart rate at the high speed, and HR' the heart rate at the low speed. A linear regression equation with VO_2 as the independent variable and activity counts as the dependent variable was then computed for each subject and used in activity count extrapolation at 3 and 6 METS.

Statistical Analysis

Receiver Operation Characteristic curves (ROC curves) were run to determine the counts per minute threshold at moderate and vigorous intensity for the normal and overweight groups (purpose 1). The cut-point selected for each intensity had the optimal value of sensitivity and specificity, and simultaneously had the largest area under the curve. A standard approach was utilized in choosing the lower threshold for activity counts corresponding to moderate intensity physical activity (Trueth et al., 2004). True and false positives classifications were also computed to determine the percent of subjects who were misclassified at each intensity for both groups. In addition, variation in counts per minute at 3 and 6 METS was also computed.

Three 2 (normal weight vs. overweight) by 3 (speed) mixed model ANOVAs (General Linear Model) were run to compare differences between heart rate, VO_2 , and counts per minute at the chosen speeds of 2, 3, and 4 mph (purpose 2). The Dunnett's Test was run as a post hoc to determine where the statistically significant difference occurred within groups for main effects. All data analysis was executed using SPSS version 17.0 (Chicago, IL) with an accepted significance level (set apriori) at $\alpha = 0.05$.

CHAPTER IV

RESULTS

The purpose of this study was to determine cut-points using the Actical accelerometer which correspond to moderate and vigorous intensity exercise in overweight or obese adults using the metabolic equivalent (METs) method of classifying intensity. In addition, this study aimed to compare cut-points that have been calculated using normal weight subjects in previously completed research with the cut-points computed in the overweight and obese subjects of this study (Diaz, 2009). The first portion of this section describes the physical characteristics of the subjects in this study and presents the physiological differences in data between groups. The second segment of this section presents and compares the cut-points for both the overweight and normal weight subjects. A comparison of cut-points in overweight subjects between the two methods of measuring intensity is also offered. Finally, an attempt to compare the cut-points between groups is presented.

Subject Characteristics

Thirty overweight or obese subjects completed this study protocol. Six overweight subjects were eliminated from final statistical analysis because oxygen uptake (VO_2) data were lower than expected, and therefore, invalid at the treadmill speeds. Four overweight subjects were added to the group from previous research at the University of North Carolina- Chapel Hill (Diaz, 2009). Therefore, the overweight or obese group

ended with a total n = 28. One normal weight subject completed testing during this research study and was added to the existing data set that was previously tested resulting in a total n = 22. The final analysis included all 50 subjects. The overweight or obese group (OW) contained 17 females and 11 males. The normal weight group (NW) contained 12 females and 10 males. Sample sizes were too small and the distribution of subjects unequal; therefore, analysis by gender were not computed. The physical characteristics of the subjects are presented in table 2. The overweight subjects were significantly older, heavier, with a greater BMI and a lower relative VO₂max. Height and absolute VO₂max were similar between groups.

Table 2. Physical characteristics of the subjects (mean ± SD).

Variable	Normal weight	Overweight
Subject number (N)	22	28
Age (years)*	24.0±4.3	32.8±9.6
Height (cm)	173.5±7.3	169.6±8.7
Body mass (kg)*	67.5±7.5	101.5±24.3
BMI (kg/m ²)*	22.4±1.9	35.3±7.9
Maximum VO ₂ (L O ₂ /min)	2.8±0.8	2.8±1.2
Maximum VO ₂ (ml O ₂ /kg/min)*	42.2±9.3	28.0±11.4

*Significantly different between groups, p < 0.0005.

The number of overweight and normal subjects who completed the stages of the exercise protocol is presented in table 3. The distribution of subjects that completed the stages of the protocol was different between groups.

Table 3. Total number of subjects that finished the protocol speeds.

	Speed (mph)						
	2	3	4	5	6	7	8
Normal weight	22	22	22	22	19	10	2
Overweight	28	28	24	12	3	2	1
Total	50	50	46	34	22	12	3

A greater amount of normal weight subjects were able to complete the faster speeds of the protocol. In addition, the majority of subjects completed 2 mph, 3 mph, and 4 mph.

Therefore, these were the speeds which were chosen for analysis between groups.

Table 4. Comparison of exercise data between normal weight (NW) and overweight (OW) groups (mean \pm SD).

	Speed (mph)	NW	OW
Heart Rate (bpm)[†]	2	89 \pm 11	103 \pm 15
	3	97 \pm 12	118 \pm 18
	4	116 \pm 14	146 \pm 23
VO₂ (ml/kg/min)*	2	9.49 \pm 1.33	9.72 \pm 2.12
	3	12.01 \pm 1.55	12.85 \pm 2.13
	4	17.02 \pm 2.20	18.62 \pm 2.93*
Activity counts (Counts per minute)^a	2	1264 \pm 403	1357 \pm 536
	3	2529 \pm 493	2604 \pm 760
	4	4382 \pm 915	4773 \pm 1522

[†]Significant interaction effect, $p < 0.0005$.

*Significant between group difference at 4mph, $p = 0.021$.

^aSignificant difference within group, between all speeds, $p < 0.01$.

The differences between groups in exercise data are shown in table 4. Heart rate and VO₂ were observed to increase at a faster rate in the overweight group compared to the normal weight group (Table 4). Heart rates were significantly greater at every speed in the overweight group compared to the normal weight group. The mean difference was 14 beats per minute (bpm) at 2 mph, 21 bpm at 3 mph, and 30 bpm at 4 mph. As speed increased, the oxygen uptake of the overweight group was greater than the of the normal weight group; however, this difference was only significant at 4 mph where the difference was 1.60 ml/kg/min (Table 4). Actical activity counts (cpm) were not significantly different between groups ($p = 0.365$) (Table 4). In summary, the exercise was more physiologically demanding for the overweight group to complete, but there was no statistical significance in Actical activity counts.

ROC Curves

The Receiver Operating Characteristic (ROC) curves used in the determination of the thresholds for moderate intensity exercise are shown in figure 1. The ROC curves used in the determination of the thresholds for vigorous intensity exercise are shown in figure 2. Separate Receiver Operating Characteristic (ROC) curves were run for each group at each intensity threshold, for a total of four curves. The diagonal line on the graphs represents the segment produced by ties, when the value for sensitivity was equal to the value for 1-specificity. The area under the curve was different for each ROC curve. For the normal weight group curves, area under the curve was 0.958 and 0.985 for the 3 MET and 6 MET intensities, respectively. For the overweight group curves, area under the curve was 0.875 and 0.968 for the 3 MET and 6 MET intensities, respectively. The area under the curves was smaller for the overweight group at both intensities, with a greater 95% confidence interval surrounding the value.

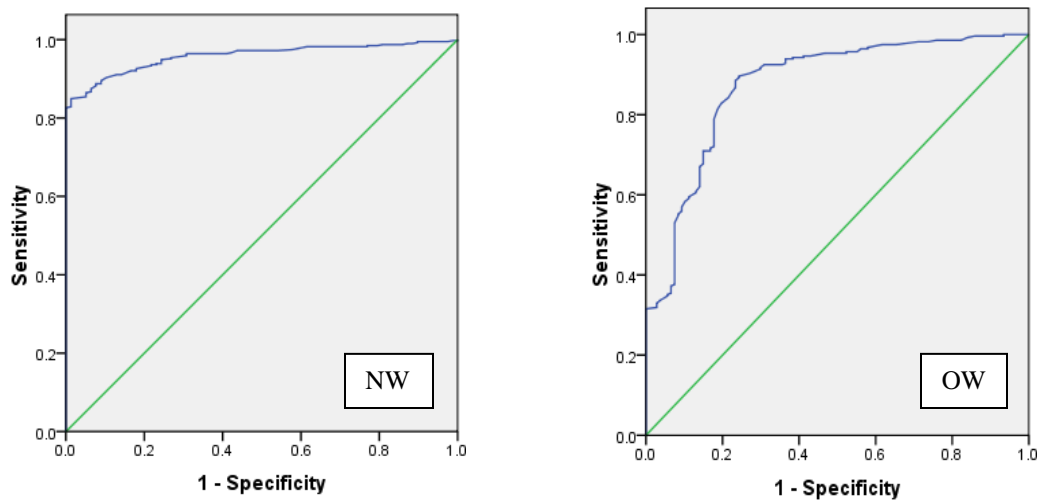


Figure 1. ROC curves comparing the normal weight (NW) and overweight (OW) counts per minute threshold for moderate intensity exercise.

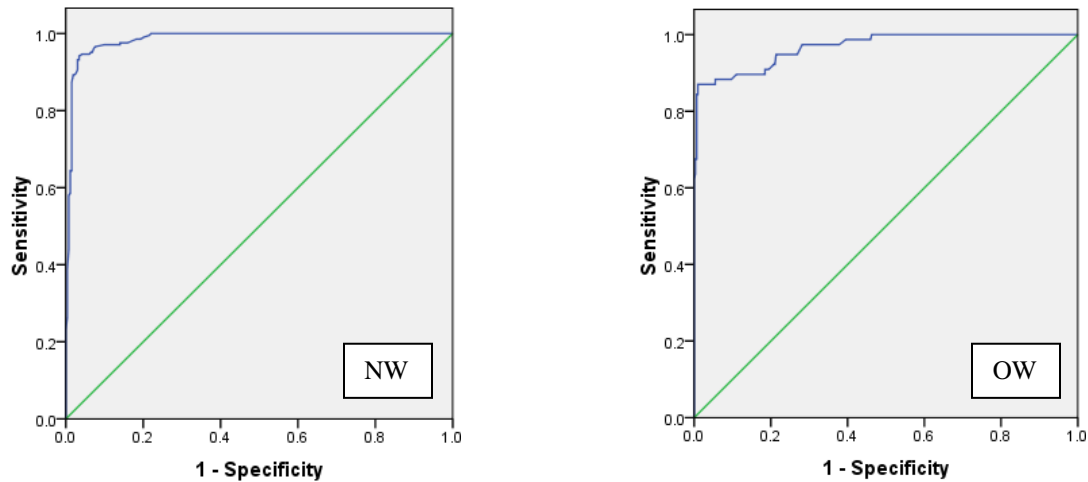


Figure 2. ROC curves comparing the normal weight (NW) and overweight (OW) counts per minute threshold for vigorous intensity exercise.

Cut-points

Individual regression equations were used to calculate activity counts at 3 and 6 METS for each subject. The cut-point chosen to represent the threshold for moderate (3 METS) and vigorous (6 METS) intensity exercise was the inflection point in the curve which maximized sensitivity and minimized specificity. The cut-points selected for the normal weight and overweight groups are presented in table 5.

Table 5. Counts per minute cut-points by group.

	Normal weight		Overweight	
	3 METS	6 METS	3 METS	6 METS
Cut-point (CPM)	1994	4381	1839	3900
95% Confidence Interval Area under the curve	0.941-0.975	0.975-0.994	0.835-0.916	0.947-0.989
Sensitivity	0.928	0.985	0.918	0.948
Specificity	0.192	0.182	0.299	0.214
Average (\pmSD) counts	3442 (1118)	8014 (1992)	3425 (1447)	7292 (2661)

The cut-point chosen to represent the threshold for moderate intensity exercise in the normal weight group was 155 CPM higher than the cut-point chosen for the

overweight group. The cut-point chosen as the threshold for vigorous intensity exercise was 481 CPM higher in the normal weight group compared to the overweight group. Several misclassifications occurred in the subjects in this study. Within the normal weight group at moderate intensity, one subject (4 %) was a false negative because CPM did not reach the definition of moderate intensity (1994 CPM). At the vigorous intensity, all normal weight subjects reached the threshold of 4381 CPM. Within the overweight group at moderate intensity, three subjects (11 %) would have been false negatives because CPM did not reach the definition of moderate intensity (1839 CPM). At vigorous intensity, three overweight subjects (14 %) would have been false positives because CPM did not reach the 3900 CPM threshold. Several misclassifications at the moderate intensity threshold also would have occurred using the cut-points developed in this study. Three normal weight subjects who were classified as moderate intensity at 3 METS actually had CPM which placed them in the vigorous intensity category. Within the overweight group, seven subjects were misclassified as exercising at moderate intensity when their CPM actually placed them in the vigorous intensity category. The average (\pm SD) activity count value at 3 METS was 3442 (1118) CPM for the normal weight group and 3425 (1447) CPM for the overweight group. The average (\pm SD) activity count value at 6 METS was 8014 (1992) for the normal weight group and 7292 (2661) for the overweight group.

CHAPTER V

DISCUSSION

The purpose of the present study was to develop cut-points using the Actical accelerometer to define moderate and vigorous intensity exercise in overweight subjects. Secondly, this study aimed to compare cut-points developed in overweight subjects with cut-points in normal weight subjects. The results of this study revealed large individual differences in cut-points with much overlap, suggesting that the difference in cut-points between overweight and normal weight adults was minimal. The moderate intensity cut-point was 8% higher for the normal weight group (1994 CPM) compared to the overweight (1839 CPM), and the vigorous intensity cut-point was 11% greater for the normal weight (4381 CPM) compared to overweight (3900 CPM) (Table 5). The results of this study also showed no differences between groups in their Actical counts at 2, 3, and 4 mph (Table 4).

Metabolic Response to Exercise

The average energy cost per kilogram body mass was similar for both the normal and overweight subjects at the slowest speeds of the exercise session (2 and 3 mph). However, oxygen uptake (VO_2) was significantly greater in the overweight group at the 4 mph stage. Heart rate values were significantly higher for the overweight group at all speeds (Table 4). This difference may be explained by the percentage of $\text{VO}_{2\text{max}}$ at which the overweight subjects were exercising, compared to the normal weight subjects.

The average VO_2max was 34% greater in the normal weight group (42.2 ml/kg/min) compared to the average VO_2max of the overweight group (28 ml/kg/min) (Table 2). Therefore, at 2 mph, the normal weight group was exercising at 23% of their VO_2max while the overweight group was at 35% of their VO_2max . At 3 mph, the normal weight group was at 29% compared to 46% VO_2max in the overweight group. Finally, at 4 mph the normal weight group increased to 40% while the overweight group increased to 67% VO_2max to complete the stage. Therefore, the exercise was harder for the overweight subjects to complete, as evidenced by greater VO_2 at the fastest speed, higher heart rates, and greater percent of VO_2max required to complete the exercise. In support, the overweight subjects were visibly fatigued and reported higher ratings of perceived exertions at test termination compared to the normal weight subjects.

Comparison to Previous Research

Lopes et al. (2009) presented cut-points in overweight and obese adults, but used the Actigraph accelerometer. The cut-point for moderate intensity exercise was 1240 CPM and 2400 CPM for vigorous intensity exercise. These thresholds are 599 CPM (33%) and 1500 (39%) CPM less than the cut-points developed for moderate and vigorous intensity exercise in the overweight group using the Actical. There are several explanations for these differences: different accelerometer devices, the resting VO_2 used in energy expenditure calculation, and the average subject age. The Actigraph accelerometer is a one-dimensional accelerometer and the Actical is an omni-directional accelerometer which can record accelerations in all directions. These differences in mechanical properties have the potential to influence accelerometer output, causing differences in CPM between devices at the same workload (Welk, 2005). In addition, the

subjects in the Lopes et al. study had resting VO_2 measured, and it was found that 1 MET was lower than the standard 1 MET value (3.5 ml/kg/min) for both the males (3.48 ± 1.15 ml/kg/min) and females (2.37 ± 0.30 ml/kg/min) of the study. Therefore, the subject's measured resting VO_2 was used to estimate MET levels. This may have contributed to the lower CPM at the intensity thresholds compared to the use of the standard 1 MET value in the present study (Lopes et al., 2009). Differences in cut-points between the present study and the Lopes et al. cut-points may also be attributed to the disparity in age and disease condition between populations. The sample population used in calibration studies must be similar in age, size, and behavioral patterns to the population of interest (Welk, 2005). The subjects used in the Lopes and colleagues study were an average of 24 years older than the overweight subjects in this study. There are differences between groups which can contribute to differences in accelerometer output: loss of muscle mass, decreased flexibility (especially of the ankle), degeneration of the joints, and decreased motor control all contribute to changes in gait (Graves et al., 2010). Calibration research is needed with overweight subject populations for each accelerometer available for use to establish intensity threshold values.

Cut-points have been established in normal weight males using the RT3 and Actigraph accelerometers during a variety of laboratory and field activities. RT3 cut-points were 1317 CPM for moderate and 2637 CPM for vigorous intensity (Rowlands et al., 2004). These values are 677 CPM lower at the moderate and 1744 CPM lower at the vigorous intensity compared to the thresholds computed in the normal weight group of the present study. Published Actigraph cut-points representing the moderate intensity threshold range from 574-2192 CPM while vigorous intensity cut-points range from

4945-6893 CPM (Freedson et al., 1998; Hendelman et al., 2000; Swartz et al., 2000).

This represents a range of disparity at the moderate intensity of 71% below to 10% above and, at vigorous intensity, between 13 and 57% above the Actical cut-points. These differences could be attributed to the activities completed by the subjects during the studies and the accelerometer used. Rowlands et al. (2004) and Swartz et al. (2000) employed free-living activities in their exercise protocol. It has been previously shown that the relationship between energy expenditure and activity counts changes when evaluated in the laboratory and field setting (Nichols et al., 2000). The present protocol utilized only laboratory treadmill walking; therefore, differences in activity counts could be attributed to the inclusion of unregulated activities. The difference in activity counts at intensity thresholds may also be caused by differences in accelerometer sensitivity. The RT3 accelerometer measures activity in three dimensions (x, y, and z planes), the Actigraph is primarily sensitive to the vertical plane, and the Actical is omnidirectional. This variation causes the Actical to be more sensitive to movement not directly in the x, y, and z planes of motion. Therefore, calibration research should be specific to the activities involved and the accelerometer device.

The results of the present study are not comparable to the majority of recently published Actical calibration research in which children were used as subjects. Differences in resting metabolic rate, height, weight, and movement patterns do not allow for comparisons between activity counts in children and adults. The results of the present study are not directly comparable to previous Actical calibration research in adults because previous authors did not calculate cut-points for changes in intensity (Rothney et al., 2008; Crouter & Bassett, 2008; Heil, 2006). In one study, Holleman et al. (2008)

published activity count thresholds at 2, 2.5, and 3 mph in an overweight population (all speeds were considered moderate intensity). The activity counts developed by Holleman and colleagues (2008) were slightly greater at both moderate (393 CPM) and vigorous (146 CPM) intensities. These differences could be explained by the type of activity performed (treadmill compared to free-living walking) because of the greater amount of variation in activity counts in free-living situations (Hendelman et al., 2000).

Comparison of Cut-Points by Weight Status

The intensity thresholds for the normal weight group presented in this study were compiled using previously obtained Actical data (Diaz, 2009). Activity counts were not significantly different between groups at 2, 3 and 4 mph (Table 4). The cut-points developed for the normal weight group were somewhat greater than the cut-points for the overweight group at both moderate (by 155 CPM) and vigorous (by 481 CPM) intensity activity (Table 5). However, these differences were small; 8% at moderate and 11% at vigorous intensity. The average activity count (\pm SD) at the 3 MET moderate intensity threshold was 3442 (1118) CPM for the normal weight group and 3425 (1447) CPM for the overweight group. The average activity count (\pm SD) at the 6 MET vigorous intensity threshold was 8014 (1992) CPM for the normal weight group and 7292 (2661) CPM for the overweight group. The standard deviations were large in both groups, which resulted from great variability in CPM. This variance in combination with the smaller areas under the curve, made the determination of the inflection point on the ROC curve (and the subsequent determination of the CPM threshold) more difficult in the overweight group. The large standard deviations also suggest why the cut-points are not different between the normal and overweight groups.

The overweight group had a greater amount of misclassifications using the developed intensity threshold cut-points (11% at 3 METS and 14% at 6 METS) compared to the normal weight group (4% at 3 METS and 0% at 6 METS). Several subjects were classified as moderate intensity by 3 METS but their CPM placed them in the vigorous intensity activity count threshold (three normal weights and seven overweight). However, there were no statistically significant differences between the overweight and normal weight activity counts at 2, 3, and 4 mph and there was a large amount of variance in cut-points for both groups. In addition, a relatively small percentage of misclassifications occurred when utilizing the developed cut-points in both the normal and overweight groups. Therefore, when utilizing the same accelerometer device manufacturer, it may be appropriate to utilize cut-points developed in a normal weight population for an overweight population (or vice versa).

There are several possible reasons that no differences in activity counts were observed between groups. The first explanation is that there was no difference between groups in stride length: which can be attributed to similar height between groups (Table 2). A second explanation is the positioning of the accelerometer device on the participants. Previous research has shown that positioning the Actigraph accelerometer region of the hip can significantly influence activity counts by 30% (Jones et al., 1999). While the positioning was standardized to the midline of the right thigh for both normal and overweight subjects, it is possible that a shift in position on the hip occurred during exercise. It is also likely that the significantly greater weight of the overweight subjects altered the motion of the accelerometer device, and subsequently, activity counts, while

positioned on the hip. Future research should seek to identify the impact of excess abdominal adiposity on accelerometer output.

Limitations

There are several limitations to this study. Two different devices were used to measure oxygen uptake (VO_2) during this study: the Parvo Medics TrueMax 2400 Metabolic Measurement System and COSMED K4b² portable measurement system. An attempt to ensure that both systems were measuring VO_2 similarly was made and the error rate was very small; Parvo Medics measured VO_2 0.03% higher than the COSMED.

Another limitation of this study was that resting VO_2 was measured for only two minutes with the subjects standing on the treadmill. In order to obtain a true resting measurement, the subjects should have had the measurement taken in a thermoneutral environment; 12 hours fasted, lying still but awake (Puyau et al., 2004). Therefore, the resting VO_2 measurement taken during this study is not reflective of true rest and 3 and 6 MET values based on resting VO_2 could not be determined. The inability to calculate true rest also lead to the use of the standardized intensity levels of 3 and 6 METS, which is a limitation of this study. The vigorous threshold of 6 METS may be perceived as “light” for one individual but as “hard” for another. However, the use of the standard 3 and 6 MET values is widespread in the literature. The utilization of alternative definitions of intensity should be considered when the measurement of resting energy expenditure is inaccurate. Another limitation to this study is the small sample size ($n = 50$). A small sample size limits the amount of power of this research.

Generalizability

The relationship of accelerometry output and energy expenditure depends on the type of activity being performed (Hendelman et al., 2000). It may therefore be unsuitable to apply cut-points developed with laboratory exercises to field based (or free living) activities because the activity count patterns during activity will be different. The exercise protocol of the present calibration study was a laboratory calibration study as subjects only completed treadmill exercise. The stride frequency was constant because of the use of the treadmill, which may lead to a different activity count pattern than free living, over-ground walking (Hendelman et al., 2000). However, the cut-points developed in the present study were based on the measurement of oxygen uptake, not treadmill speed. Therefore, caution should be employed when applying these cut-points to studies utilizing free living walking and jogging activities.

Conclusion

Thresholds have been developed for accelerometry which can categorize the activity as light, moderate, or vigorous intensity. Thresholds vary by the populations they are developed from. For overweight or obese individuals wearing the Actical accelerometer, the results suggest that the cut-points are 1839 CPM for moderate and 3900 CPM for vigorous intensity exercise. For normal weight individuals wearing the Actical, the cut-points appear to be slightly higher, 1994 CPM for moderate and 4381 for vigorous intensity exercise. These thresholds resulted in a relatively low number of misclassifications, with one normal weight and three overweight subjects determined to be false negative classifications at moderate intensity. Therefore, it was harder to classify the activity intensity of overweight subjects compared to normal weight subjects.

The first purpose of this study was exploratory; therefore, no hypothesis was presented. The cut-point values for overweight or obese individuals are presented in Table 5. The secondary purpose of this study was to evaluate cut-points in overweight or obese adults with normal weight adults. It was hypothesized that there would be no difference in cut-points in overweight or obese adults compared to normal weight adults. Based upon the results, this hypothesis was accepted.

Future Directions

The development of activity count thresholds corresponding to different levels of activity intensity is an important aspect of physical activity research. These cut-points are relied upon when attempting to analyze the effectiveness of an activity-based intervention, or in observing if an individual or group is meeting the recommendations for physical activity to impact health. The first direction this line of research should pursue is the accuracy of the standard $1 \text{ MET} = 3.5 \text{ ml/kg/min}$ value in calculating the 3 and 6 MET thresholds. Several studies have revealed that this estimation of resting energy expenditure results in an overestimation (Byrne et al., 2005; Lopes et al., 2009). Future research should involve measuring each individual subject's resting energy expenditure (VO_2) and utilizing this value in the calculation of 3 and 6 METS. The use of measured rest could lead to a different number of activity counts at certain physical activity intensities.

Future research should also investigate the use of other measures of activity intensity as the definitions of thresholds. If research is measuring VO_2 simultaneously with activity counts, the use of percent $\text{VO}_{2\text{max}}$ may be appropriate to define activity intensity. Previous work has established cut-points based on maximum oxygen uptake

(VO₂max) relative to the individual for moderate and vigorous intensity exercise and 40% VO₂max and 65% VO₂max, respectively (Skinner & McLellan, 1980). These cut-points are based on measurements of VO₂, heart rate, respiration, and lactate (Skinner & McLellan, 1980). This alternate means of assessing exercise intensity may be more accurate and lead to better exercise prescriptions (and subsequently, better health and weight loss outcomes) in the overweight and obese population; however, this method is more equipment intensive. Future research should also aim to determine the most accurate method to analyze accelerometry data, as there are various ways used in different research. Most calibration studies assume that there is a linear relationship between accelerometry output and energy expenditure (Welk, 2005). However, not every monitor is linearly related to movement, especially at high speeds (King et al., 2004). Future research should determine if the use of curvilinear functions provides a better fit for accelerometry data, and subsequently afford more accurate estimations of energy expenditure throughout an entire range of intensities than linear regression equations (Welk, 2005).

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