CALIBRATION OF THE ACTICAL ACCELEROMETER IN ADULTS

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ABSTRACT

JASON DIAZ: Calibration of the Actical Accelerometer in Adults

(Under direction of Robert McMurray, PhD)

The purpose of this investigation was to develop cut-points for the Actical accelerometer in adults that correspond to light, moderate, and vigorous physical activity using a percentage of maximal oxygen uptake (VO_2max). Twenty five young adults completed a progressive submaximal exercise test on a treadmill wearing an Actical accelerometer while oxygen uptake was measured. The VO_2max based cut-points for light-to-moderate was 4952 counts per minute (cpm), for moderate-to-vigorous intensity was 9714 cpm. VO_2 based cut-points were significantly greater than MET based cut-points. The results of this investigation suggest that MET definitions of moderate and vigorous intensity are too light for young adults and may lead to misclassification of physical activity levels. The results also suggest that individual calibration of the Actical accelerometer may be needed due to the high variability of VO_2max based cut-points.

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CHAPTER I

INTRODUCTION

Physical activity is defined as “any bodily movement produced by the contraction of skeletal muscle that results in substantial increases in energy expenditure” (Casperson et al. 1985). Physical activity is essential to maintaining a healthy life as it decreases the risks of chronic diseases such as heart disease and type-2 diabetes, and provides several health benefits including weight management, mood elevation and building of healthy bones, muscles and joints. The growing awareness of the importance of physical activity has led to the creation of public health guidelines. Healthy People 2010 are a set of objectives created by the U.S. Department of Health and Human Services to ensure good health and long life. One of the objectives of Healthy People 2010 is to increase the number of adults who engage in moderate physical activity at least 30 minutes per day on most days of the week. Healthy People 2010 also aims to increase the number of adults who engage in vigorous activity three or more days per week for 20 minutes or more. Several large scale epidemiological studies have shown most adults do not meet the recommended amounts of physical activity (CDC 2003, Jones et al. 1998, Pratt et al. 1999). However, the use of self-reports in order to assess physical activity levels within these epidemiological studies are imprecise and provide inaccurate estimates of adult physical activity levels.

Accurately measuring activity levels has been a difficult task due to the complexity of physical activity. Various methods have been used to assess physical activity, including self-reports, direct observation, and activity monitors. Most epidemiological studies use subjective measures like self-reports that provide inaccurate estimates of frequency, duration, and intensity of physical activity (Shepard 2003). More accurate assessment of physical activity is important in determining valid statistics of adults meeting physical activity guidelines and aid in determining the appropriate intensity levels for attaining health benefits. In an attempt to improve the accuracy of physical activity measurement, activity monitors that objectively measure physical activity have been developed.

One of the most frequently used activity monitors in research today is the accelerometer. Accelerometers are small, light weight devices worn around the hip, ankle or wrist that detect and record any motion or acceleration in single or multiple planes. Accelerations are recorded as activity counts, and due to time sampling capabilities of accelerometers, can be used to assess frequency and duration of physical activity. Additionally, accelerometers provide estimates of intensity and energy expenditure. Several types of accelerometers exist today, differing by anatomical positioning and number of planes of measure. Because of these disparities, each accelerometer measures and records different count values for physical activities. Therefore, calibration studies are necessary for each accelerometer in order to determine values produced by various physical activities.

Within calibration studies, subjects are asked to perform a variety of physical activities at different intensity levels in a field or laboratory settings. Based upon the results, researchers develop regression equations and cut-points or thresholds to distinguish intensity levels that correspond to public health recommendations for physical activity and allow for estimation of energy expenditure. Most accelerometer calibration studies employ the metabolic equivalent (MET) to classify intensity as sedentary (1-1.5 METs), light (1.6-2.9 METs), moderate (3-6 METs) or vigorous (>6 METs)(Crouter et al. 2006). However, MET levels are affected by age (Morris et al. 1993), weight (Spadano et al. 2003) and comorbidities (Woolf-May and

Ferrett 2008) and have been show to overestimate resting energy expenditure and underestimate energy expenditure during exercise in adults (Byrne et al. 2005). Miscalculation of intensity levels and inaccurate estimates of physical activity levels may result in insufficient exercise prescription to elicit health benefits and inaccurate physical activity level estimates. Therefore, using METs to classify intensity levels that correspond to activity counts may not be appropriate. Classifying intensity as light (<40%), moderate (40-65%), or vigorous (>65%) based on a percentage of maximal oxygen uptake (VO_2 max) may provide more accurate estimates of intensity and energy expenditure as the intensity thresholds are based upon measurement of oxygen uptake (VO_2), heart rate, and blood lactate (Skinner and McLellan 1980).

One accelerometer becoming more widely used in research is the Actical (Mini Mitter, Bend, OR). The Actical accelerometer is an omnidirectional accelerometer that has the ability to measure accelerations in multiple planes, but is most sensitive to vertical movement. To date, four Actical calibration studies have been conducted on children (Corder et al. 2005, Evenson et al. 2008, Pfeiffer et al. 2006, Puyau et al. 2004) and three calibration studies on adults (Klippel and Heil 2003, Heil 2006, Crouter and Bassett 2008). However, the adult Actical calibrations created regression equations based on METs in order to classify intensity. Since the use of METs may provide inaccurate estimates of physical activity levels, further research is needed in order to determine appropriate adult cut-points when using the Actical accelerometer.

Purpose

The purpose of this study is to complete a calibration of the Actical accelerometer to determine adult cut-points that correspond to light, moderate and vigorous intensity levels using a percentage of VO_2max. The second purpose is to compare these cut-points to the standard MET cut-points for each intensity level.

Research Questions

1. How many activity counts from the Actical accelerometer delineate light to moderate intensity activity in adults?
2. How many activity counts from the Actical accelerometer delineate moderate to vigorous intensity activity in adults?

Limitations

1. Small sample size reduces the power and generalizability of this study.
2. Cut-points determined by fixed ambulation of treadmill exercise may not apply to real life activities as the relationship between activity counts and energy expenditure differ in free-living conditions.

Delimitations

1. Only healthy, young adult subjects will be used for this study.
2. Subjects will be recruited from the University of North Carolina.

CHAPTER II

LITERATURE REVIEW

Physical activity is essential for living a healthy life. However, difficulties in measuring physical activity have led to discrepancies in identifying the optimal dosage needed to attain the proposed health benefits as well as discrepancies in determining the number of adults who regularly engage in physical activity. Physical activity is difficult to measure because it is a very broad construct that may include measurements of mode, frequency, intensity, duration, and energy expenditure. This review of literature will focus on the measurement issues regarding physical activity. This review of literature will first begin with an overview of the health benefits of physical activity including a discussion on current research regarding the dose-response relationship between physical activity and health outcomes. The second section of this literature review will focus on the current recommendations for physical activity, as well as presentation of research regarding the percentage of adults meeting physical activity recommendations. Although most studies conclude the majority of adults are not meeting recommended levels of physical activity, measurement issues have led to inconsistencies in findings. Therefore, the next section of this review describes the method most commonly used to classify physical activity intensity levels as well as the various techniques used to measure physical activity levels that have led to the discrepancies. Of primary focus is the description of accelerometers and the methods used to calibrate them. This literature review will then conclude with a discussion of the Actial accelerometer and recent attempts to calibrate the Actical accelerometer.

Health Benefits of Physical Activity

Physical activity is associated with greater longevity and a decreased risk for several chronic diseases. Recent research suggests that physical activity is inversely related to disease outcomes including cardiovascular disease, type 2 diabetes, stroke, hypertension, cancer, depression, and dementia (Kesaniemi et al. 2001). However, the optimal dose to elicit these health benefits remains unclear. The dose of physical activity can be interpreted in many different ways including activity type, frequency, intensity, duration, and accumulation. To aid the general public in determining the optimal dosage of physical activity, several public health recommendations have been created. Both the Center for Disease Control and Prevention (CDC) and American College of Sports Medicine (ACSM) recommend adults between the ages of 18-65 should engage in moderate intensity physical activity for at least 30 minutes for five days per week or vigorous intensity physical activity for at least 20 minutes, three days per week (Haskell et al. 2007). The physical activity recommendations of the CDC and ACSM are based on epidemiological evidence of a dose-response relationship that exists between physical activity and health outcomes, as the greater the physical activity dose, the greater health benefits. Thus, vigorous physical activity will yield greater health benefits than moderate physical activity (Lakka et al. 1994; Sesso et al. 2000), as recent research has shown for every 1 MET increase in exercise intensity, there is an 8-17% reduction in all causes of mortality (Swain and Franklin 2006).

Although vigorous physical activity produces the greatest health benefits, attaining the recommended dose of vigorous physical activity may not be feasible for individuals of low exercise capacity. Therefore, the CDC and ACSM created moderate intensity physical activity recommendations designed for previously sedentary individuals. Moderate physical activity has been show to produce favorable changes in lipids, blood pressure, insulin sensitivity, and c-reactive protein (Bassuk and Manson 2003), as well as reduce the mortality risk of all of causes of mortality (Buksh 2005). In addition, moderate physical activity has also been shown to produce many of the health changes similar to vigorous physical activity. Manson et al. (1999) and Hu et al. (1999 & 2000) examined the incidence of coronary events, type 2 diabetes and stroke in over 70,000 female nurses during an eight year follow up period. Each nurse was asked to self-report physical activity three times during the eight-year follow up, with each physical activity being classified as vigorous (≥ 6 METs), non-vigorous (≤ 6 METs) or walking (2.5-4.5 METs). Manson et al. found that moderate physical activity like walking, and vigorous physical activity equally reduced the risk of coronary events by 30-40%. Similarly, Hu et al. (1999 & 2000) found that walking resulted in risk reductions for type 2-diabetes and stroke equal to the risk reductions produced by vigorous physical activity.

The inverse relationship between moderate physical activity and health outcomes has not been consistently shown. The Harvard Alumni Study (Sesso et al. 2000) obtained self-reported incidence of coronary heart disease as well as self-reported levels of physical activity in 12,516 men, and found only vigorous activities to be inversely associated with risk of coronary heart disease ($p = 0.02$). In a study of 1453 men, Lakka et al. (1994) found that the risk of myocardial infarction was only reduced in men who performed vigorous exercise. The inconsistencies in the findings of the moderate activity health benefits are due largely to the methods used to measure and classify physical activity. Most epidemiological studies examine the health effects of physical activity through the use self-reports, which have been show to provide inaccurate estimates of physical activity levels (Shepard 2003). Epidemiological studies also employ the use of METs to classify intensity levels, which has been shown to underestimate and overestimate resting energy expenditure and underestimate energy expenditure during exercise (Byrne et al. 2005). Nonetheless, individuals who regularly participate in any type of physical activity are of better health than sedentary individuals.

Physical Activity Levels

Despite the known health benefits of physical activity, several large public health surveillance systems have shown that many adults are not meeting the current physical activity guidelines (CDC 2007). The Center for Disease Control and Prevention (CDC) annually conducts the Behavioral Risk Factor Surveillance System (BRFSS) to assess health risk behaviors and preventive health practices including levels of physical activity. Each year the BRFSS performs a telephone survey on more than 350,000 adults. In the survey, participants are asked if they perform moderate or vigorous physical activity in a usual week for at least 10 minutes at a time. If they perform moderate or vigorous physical activity, the participants are then asked to estimate how much time per day and per week they spend doing those activities. Based on these questions, the 2007 BRFSS estimated that 50.8% of adults did not meet the recommendation for accumulating 30 minutes of moderate physical activity five or more days per week or 20 minutes of vigorous physical activity three or more days per week. Similar results were found by the 2007 National Health Interview Survey (NHIS) in a survey of 23,393 adults (CDC 2007). The NHIS is another public health surveillance system conducted by the CDC that involves a personal household interview conducted by trained interviewers. Within the interview, participants asked how many times per day, week, month and year they perform vigorous physical activity for at least 10 minutes that causes heavy sweating or large increases in breathing or heart rate. The NHIS found that 61% of adults report never haven participated in vigorous physical activity lasting 10 or more minutes per week.

Studies using objective measurement of physical activity have also been used to investigate the percentage of adults who are meeting the current physical activity recommendations. Troiano et al. (2008) used accelerometer data of 11,196 subjects from the 2003-2004 National Health and Nutritional Examination Survey (NHANES) to determine the percentage of children and adults meeting both moderate and vigorous recommendations. Subjects wore an MTI Actigraph accelerometer for one to four days. Intensity of physical activity was classified based upon threshold counts of 2020 for moderate activity and 5999 counts for vigorous activity. The percentage of adults who met the moderate physical activity recommendations ranged from 5.4-37.9% depending on age and gender, with physical activity significantly lower in females than males and significantly decreased with age. The percentage of adults who met the vigorous physical activity recommendations ranged from 0.1-1.9%, also depending on age and gender. Hagstromer et al. (2007) assessed physical activity levels of 1114 adults using the Actigraph accelerometer. Each subject wore the Actigraph during waking hours for seven consecutive days. Using cut point values for moderate (1952-5724) and vigorous physical activity (> 5724), Hagstromer et al. found that only 52% of participants accumulated 30 minutes of at least moderate physical activity per day. Of those who achieved 30 minutes of moderate physical activity per day, only 1% accumulated 30 minutes of physical activity through bouts lasting 10 minutes or longer. Dinger and Behrens (2006) also used accelerometry to assess physical activity of 454 young adults between the ages of 18-30. All subjects wore the Actigraph for seven consecutive days during waking hours. Using the same cut-points as Hagstromer et al., approximately 53% of the participants accumulated the moderate recommendations of five days per week, while only 4.6% met vigorous recommendations of three days per week. When moderate and vigorous physical activity was considered in sessions lasting at least 10 minutes, 96% of the participants did not meet the weekly recommendations. In addition, 45% of participants did not accumulate moderate recommendations in 10 min sessions on any day of the week. Based upon the results of these studies examining adult physical activity levels, it can be concluded that the majority of the adults are not meeting the current health recommendations for physical activity.

Classifying Intensity Levels

Intensity level and energy expenditure are commonly estimated in public health surveillance and dose-response relationship studies by metabolic equivalents (MET). One MET is defined as the quantity of oxygen consumed by the body under resting condition and is equal to 3.5 mL of oxygen/kg per minute (Morris et al. 1993). The derivation of one MET is unknown, yet has been widely used by researchers and clinicians to quantify physical activity intensity levels in a variety of populations. Most researchers classify sedentary activity as 1-1.5 METs, light activity as 1.6-2.9 METs, moderate activity as 3-6 METs and vigorous activity as greater than 6 METs. Current physical activity recommendations also employ METs as ACSM recommends a healthy adult should accumulate 450- 750 MET-minutes per week. To aid in the comparison of physical intensity levels across public health surveys, Ainsworth et al. (2000) created the "Compendium of Physical Activities", in which physical activities are given a coding scheme that corresponds to a specific MET level based upon laboratory and field studies. Activities range from sleeping (0.9 METs) to running (18 METs). However, Ainsworth cautions that the MET system does not take into account individual differences that may alter estimated intensity or energy expenditure.

Several recent studies have demonstrated the inaccuracy of METs due to individual differences. Byrne et al. (2005) measured resting metabolic rate by indirect calorimetry using a ventilated hood system in 769 healthy males and females. The commonly accepted resting 1 MET value of 3.5 mL O_2/kg/min was found to overestimate the actual resting VO_2 value by 35%. Using a multiple regression analysis, Byrne et al. also found that body composition accounted for 62% of the resting VO_2 variance, while age accounted for 14% of the resting VO_2 variance. In the same study, Byrne also assessed the energy cost of walking at 5.6 km/h, a speed defined as 3.8 METs, through indirect calorimetry. Measured energy cost was 22% higher than the MET level energy cost, while measured VO_2 was higher than (15.88 mL O_2/kg) MET estimated VO_2 (13.3

mL O_2/kg). In a study of energy cost in seventeen 12 year old girls, Spadano et al. (2003) measured resting metabolic rate for 30 minutes using the ventilated hood system. Energy cost was also assessed using indirect calorimetry during sitting, standing, and walking on a treadmill at 2.0 mph, 3.0 mph, and 3.0 mph with 10% grade. Body weight was found to be a significant predictor of MET value as it accounted for 25%, 39%, and 63% of variance in MET values during walking at 2.0 mph, 3.0 mph and 3.0 mph at 10% incline respectively. Woolf-May and Ferrett (2007) investigated the effect of comorbidities on MET values using thirty-one post myocardial infarction subjects and 19 non-cardiac subjects. Each subject performed a 10 meter shuttle walking test while energy cost was measured through a portable metabolic system. A comparison of MET values revealed that post myocardial infarction subjects had significantly higher METs (3–8 METS) than non-cardiac subjects (2–5 METS) at 1.12 to 4.16 mph ($p < 0.001$).

Despite the evidence that MET values are significantly affected by individual differences such as age, body weight, and comorbidities, METs are still widely used in research today. Special consideration should be taken for each individual when attempting to estimate intensity level or prescribe exercise. For example, walking at a speed of 4.0 mph (4 METs) may be considered moderate for a sedentary adult but light for an aerobically trained individual. This is because exercise intensity based on MET values may not be representative of an adult with an exercise capacity >10 METs. Moderate and vigorous MET values provide inaccurate estimates of exercising energy expenditure and may not truly reflect 40% and 65% of VO_2max. Other methods for classifying exercise intensity, such as heart rate reserve, should be incorporated as they have a stronger relationship with percentage of VO_2 (Strath 2000) and therefore may provide more accurate estimates of intensity level.

Measurement of Physical Activity

Many of the inconsistencies among studies examining current physical activity levels and studies investigating the relationship between physical activity and health outcomes are due to the differences in methodology. Various methods have been used to assess physical activity, each with their own distinct advantage and disadvantage. Measurement methods include subjective measures such as self reports and objective measures such as, direct observation and activity monitors. However, the lack of a gold standard has made it difficult to determine the validity of each method of measurement (Goran 1998). A description of each method is provided below.

Self-Reports

Self-reports are the most widely used method of physical activity assessment. Types of self-reports include the use of activity logs, diaries, and recall questionnaires. Activity logs and diaries require the subject to provide a detailed record of all physical activity within a designated time frame. Subjects may be asked to record mode, duration, and intensity of all physical activity they engaged in. Recall questionnaires require the subject to recall details of physical activity for time frames ranging anywhere from one day to one year, or the subject may be asked to describe their lifetime exercise habits. Recall questionnaires can be self administered or administered by an interviewer over the phone or in person.

Epidemiological studies rely heavily on self-reports as they are easy to administer and are of low cost. However, due to their subjective nature, there are several limitations involved with self-reports. Self-reports are cognitively challenging to both children and adults as they have difficulty recalling frequency, intensity and duration of physical activity (Durant and Ainsworth 1996, Baranowski 1988). Most subjects are able to accurately recall vigorous physical activity because it is involves more structured exercise (Bassett et al. 2000). Difficulty arises when subjects are asked to recall light or moderate physical activity, like walking or household chores, that are more routine, intermittent or spontaneous. For example, Yore et al. (2007) examined the validity and reliability of the BRFSS physical activity questionnaire by comparing it to objectively measured physical activity. Sixty subjects wore an accelerometer and pedometer for 7 days during waking hours and answered the BRFSS survey on three separate occasions. The reliability (kappa) of the survey for moderate activity was 0.35-0.53 compared to 0.80-0.86 for vigorous activity. Furthermore, the validity of the BRFSS survey for assessing moderate to vigorous physical activity was 0.17-0.22, using the accelerometer as the standard. Similarly, Hayden-Eade et al. (2003) found moderate activity to have a weak correlation ($r = 0.31$) between a 7 day physical activity recall and the TriTrac R3D accelerometer, and stronger correlation ($r = 0.78$) for vigorous activity.

Numerous studies have also found walking, the most common moderate activity, the least reliable to recall. Both men and women have been shown to underestimate walking frequency, intensity and distance (Tudor –Locke & Myers 2001). Ainsworth et al. (1993) and Richardson et al. (1994) compared the results of two commonly used physical activity surveys to six 48 hour physical activity records and fourteen 24 or 48 hour Caltrac accelerometer readings. Both physical activity surveys were found to significantly differ ($p< 0.05$) from direct validation of walking as distance and energy expenditure were underestimated. Bassett et al. (2000) compared self reported daily walking distance to values obtained from an electronic pedometer in 96 subjects and found self-reports significantly underestimated walking distance ($p = 0.0001$). The discrepancies in self-reported moderate physical activity are due in large part to the inability of assessment tools to capture moderate activities. For example, the BRFSS asks subjects report how often they perform moderate to vigorous physical activity for at least 10 minutes that results in an increase in breathing or heart rate. This type of questions failed to capture intermittent light or moderate physical activities that are most common among sedentary populations. Self-reports also suffer from significant reporting bias as social desirability and social approval influence self reported physical activity (Adams et al. 2005). Despite the limitations of self-reports, they remain the most prevalent method for assessing physical activity in large populations due to their relative ease and inexpensive cost.

Direct Observation

Direct observation is a technique that has been used to assess physical activity levels primarily in children. Direct observation is the process of watching and recording what an individual does in a natural setting without interference. An individual can be observed within different social and physical environments, allowing for study of contextual variables. The strategy behind direct observation involves momentary time sampling, as events are coded following a specific time interval. For example, Pate et al. (2008) examined physical activity in children by coding activity at 5 second intervals on a scale of 1-5 with 1 indicating motionless and 5 indicating fast movement. Intervals recorded as 1 were considered sedentary activity and intervals coded as 5 were considered moderate to vigorous physical activity. Thus, coding and time sampling allow for measurements of intensity as well frequency and duration of physical activity. Studies comparing direct observation scores to heart rate and oxygen consumption have yielded moderate to strong correlations; $r = 0.61$- 0.91 (Sirard and Pate 2001). Despite the strong correlations, direct observation is rarely used as method for studying adult physical activity levels. Direct observation is very time consuming and requires substantial observation time in order obtain sufficient data. Direct observation also requires significant training on coding procedures, is subject to coder bias and is prone to subject reactivity. Reactivity is the change in activity patterns in response to participants knowing their activity patterns are being observed. Direct observations have rarely been used in adults.

Pedometer

Pedometers objectively measure physical activity by recording individual step counts. The pedometer is a small, inexpensive unit worn around the waist in line with hip. Vertical displacement of the hip is detected by the device and recorded as steps. Recent advances in electronic pedometers now allow for pedometers to estimate distance traveled and energy expended. However, pedometers do not have time sampling capabilities and therefore cannot measure frequency or intensity of physical activity. In addition, pedometers are not reliable for measuring daily living activities due to inaccuracies at slow and fast walking speeds (Bassett et al. 1996; Crouter et al. 2003).In a study by Bassett et al. (1996), the accuracy of five pedometers was assessed during free living conditions and treadmill walking at different speeds. Bassett et al. found that at walking speeds of 2.0 mph, pedometers underestimated step counts by 50-75%. Crouter et al. (2003) assessed the accuracy and reliability of 10 pedometers during walking speeds of 2.0, 2.5, 3.0, 3.5 and 4.0 mph on a treadmill. Crouter et al. found most pedometers underestimated step counts and overestimated distance at slower speeds, and underestimated distance at higher speeds. Nonetheless, pedometers have been found to be highly correlated with directly observed physical activity (Saris and Binkhorst 1977). Also, subjcets have shown little negative reactivity to pedometers (Ozdoba et al. 2004) and due to their noninvasiveness and low costs pedometers may be one of the best ways to objectively measure physical activity.

Heart rate monitors

Heart rate monitoring is another objective measure of physical activity that has been used to assess physical activity (Strath et al. 2000, Wareham et al. 1997). Heart rate monitoring does not directly measure physical activity but is reflective of the overall stress placed upon the cardiorespiratory system during physical activity. The underlying assumption of heart rate monitoring is that a liner relationship exists between heart rate and oxygen uptake. Therefore, adults with higher heart rates throughout the day have higher levels of physical activity (Durant et al. 1992). The validity and reliability of heart monitors has been established as Durant et al. (1993) reported within day intraclass correlations of 0.92 and between day intraclass correlations of 0.81 following 12 hours of continuous heart rate monitoring. Despite the reported reliability, there are several limitations to heart rate monitoring. One major limitation is that changes in heart rate are not always related to physical activity. Emotional stress or changes in body temperature can influence heart rate (Saris 1986). Also, an individual's heart rate will continue to remain elevated following vigorous activity, leading to overestimations of time spent being active. Another limitation of heart rate monitoring is individual differences, as more fit individuals will have lower heart rates while less fit individuals will have higher heart rates. Furthermore, activation of different muscle groups and the type of muscle contraction can elicit varying heart rate responses as well. Another limitation is heart rate monitors must be worn for extended periods of time because heart rate monitoring during limited portions of the day provide biased estimates of overall heart rate (Durant et al. 1993). All day heart monitoring may serve as an inconvenience to subjects as it may pose discomfort.

Accelerometer

Accelerometers are electronic activity monitors that measure acceleration forces. Acceleration is defined as the change in speed in respect to time and is measured in gravitational acceleration units (g). Accelerometers typically measure accelerations ranging from 0.1 – 10 g in sampling frequencies between 1 to 64 Hz (Chen and Bassett 2005). Most accelerometers consist of a cantilever beam that compresses piezoelectric crystals when an acceleration occurs, which in turn produces a charge equivalent to the acceleration. An analog to digital converter converts the charge produced by the piezoelectric crystals into raw activity counts. Accelerations can be recorded in self-initiated epochs (time periods) ranging from 1 second to several minutes and stored in internal memory for several weeks and downloaded onto a computer program.

There are several types of accelerometers commercially available today that are constructed using the same basic principles, but differing in filter and processing characteristics. The most widely used accelerometers include the uniaxial Actigraph (Actigraph, Pensacola, FL), formerly known as the Computer Sciences and Applications Inc. (CSA), the BioTrainer (IM Systems, Baltimore, MD), the Triaxial RT3 (Stayhealthy In., Monrovia CA), and the omnidirectional Actical (Mini Mitter, Bend, OR). Uniaxial accelerometers record accelerations in a single, vertical plane while biaxial accelerometers measure accelerations in two orthogonal planes. Triaxial accelerometers record accelerations in three planes, vertical, mediolateral and anteroposterior. Omnidirectional accelerometers measure accelerations in multiple planes but are most sensitive to the vertical plane. Theoretically, accelerometers that measure in multiple planes should provide a more accurate assessment of bodily movements than uniaxial accelerometers. However, most studies report a strong correlation between uniaxial and multiple axis accelerometer activity counts (Trost et al. 2005).

The major issue regarding accelerometers is what to do with the raw activity count data produced by each accelerometer. Activity counts provide an overall measurement of bodily movement. Converting counts into more meaningful measures like energy expenditure and time spent in light, moderate or vigorous intensities is an important research function. The procedure in which activity counts are converted into other measures of physical activity is termed a value calibration study (Welk 2005). Value calibration studies determine validity with respect to their ability to measure intensity and energy expenditure, and are necessary for each accelerometer due to mechanical differences that exist between each device. Value calibration studies involve subjects performing various physical activities at different intensity levels in either a field or laboratory setting. In order to determine the relationship that exists between energy expenditure and activity counts, indirect calorimetry or double labeled water are typically used as the criterion measure. Based upon the raw activity counts, energy expenditure is estimated using METs and compared to criterion measures. Researchers then employ linear regression equations to develop cutoff points that correspond to different intensity levels. Both field and laboratory calibration studies are required for each accelerometer because they produce different counts for a given activity.

Laboratory calibration studies typically involve graded exercise tests using ambulatory activities, while measuring oxygen uptake through a metabolic system. In a calibration study of the Actigraph (CSA at the time), Freedson et al. (1998) used twenty-five males and twenty-five females to develop cut-points that correspond to light, moderate, hard or very hard intensity. Each subject walked at speeds of 4.8 km/h and 6.4 km/h and jogged at a speed of 9.7 km/h. Subjects performed each stage for 6 minutes, and then rested 5 minutes before performing the next stage. While completing each stage, subjects wore the CSA accelerometer at their right hip and open circuit spirometry was used to measure oxygen uptake. Using oxygen uptake obtained during the last three minutes of each stage, MET levels were calculated by dividing VO_2 by 3.5 mL/kg/min. MET levels were then used in a liner regression to create cut-points for light (<1951 counts per minute), moderate (1952-5724 cpm), hard (5725-9498 cpm) and very hard (9499 cpm) intensity.

Nichols et al. (1999) conducted a similar calibration study on 60 adult subjects using the Tritrac accelerometer, now known as the Triaxial RD3. Each subject was required to walk at speeds of 4.8 km/h, 6.4 km/h and 9.7 km/h at 5% grade for 5 minutes per stage, with a 1 minute rest between each stage. A Tritrac accelerometer was worn around each hip and energy expenditure was measured using indirect calorimetry. Only data obtained during the 4^{th} and 5^{th} minutes of each stage were used for analysis. A regression analysis was then used to determine cut-points that correspond to intensities of MET values of light (2-3.9 METs), moderate (4-7 METs) and vigorous (>7 METs) intensity. Cut-points for the Tritrac accelerometer were reported as 650-1771, 1772-3454, and ≥ 3455 for light, moderate, and vigorous intensity respectively.

Field based calibration studies involve activities that are more generalizable to activities of daily living. Activities include household tasks or recreational activities that can be static or dynamic. Hendelman et al. (2000) assessed twenty-five subjects during both household tasks and recreational activities while wearing a CSA accelerometer on their right hip and Tritrac accelerometer on their left hip. Each subject completed three exercise sessions. The first session consisted of walking on an indoor track at a self selected leisurely, comfortable, moderate, then brisk pace for 5 minutes each, with 5 minutes of rest between each bout. The second session consisted of the subjects playing two continuous holes of golf while using a pull cart to carry their golf clubs. The third session consisted of a series of household tasks; dusting, vacuuming, mowing the lawn, washing windows and planting shrubs for 5 minutes each. Oxygen uptake was measured during each session using a portable metabolic measurement system. Using a regression analysis, cut-points were developed for the CSA and Tritrac accelerometer that correspond to light, moderate and vigorous MET levels (1-3 METs, 3-6 METs, 6-9 METs respectively). CSA counts for all activities less than 190.6 were classified as light, between 190.7 and 7527.7 were classified as moderate and greater 7528.8 than were classified as vigorous. Tritrac counts for all activities less than 168 were considered light, between 168 and 2904.2 were considered moderate and greater than 2904.3 were considered vigorous. In another field-based calibration study using the CSA accelerometer, Swartz et al. (2000) measured seventy subjects while performing one to six activities. Activities were classified as yard work (e.g. lawn mowing), occupational (e.g. unloading boxes), housework (e.g. laundry), family care (e.g. caring for small children), conditioning (e.g. light calisthenics), and recreation (e.g. doubles tennis). Each activity was performed for 15 minutes, with a total of 5-12 subjects tested per activity. While performing each activity, each subject wore CSA accelerometer on their right hip and around their non-dominant wrist and a portable metabolic measurement system to measure oxygen uptake. Following data collection, regression analyses were used to predict METs from only CSA hip counts, CSA wrist counts and then wrist and hip counts combined. Cut-points using only hip counts were as follows: light (< 574), moderate (574-4945), vigorous (>4945).

The accuracy of the cut-points developed by Freedson, Nichols, Swartz, and Hendelman has been assessed by several research studies. Ainsworth et al. (2000) assessed physical activity in 83 subjects during a 21 day period. Each subject wore a CSA accelerometer and kept a 48-item physical activity log for 21 days and completed a telephone survey once a week for three weeks. The cut-points of Freedson, Swartz and Hendleman were used to classify CSA counts as light, moderate, or vigorous and compared to physical activity log and survey item estimates of intensity. Correlations coefficients between physical activity logs and CSA scores ranged from $r = 0.24\text{-}0.32$ ($p < 0.05$) for moderate activity and $r = 0.31\text{-}0.36$ ($p < 0.01$) for vigorous activity. Correlation coefficients between survey items and CSA scores ranged from -0.01 – 0.03 for moderate activity and from 0.31-0.33 ($p < .01$) for vigorous activity depending on the cut-point. Strath et al. measured 10 adults who completed physical tasks in a field setting for 5-6 continuous hours while wearing a CSA accelerometer and portable metabolic measurement system to measure oxygen uptake. Time spent in light, moderate, and vigorous activity were estimated from the cut-points of Freedson, Nichols, Swartz and Hendelman and evaluated using oxygen uptake as the criterion method. Freedson cut point's overestimated light activity by 13% and underestimated moderate activity by 60%. Nichols cut point's overestimated light activity by 12% and overestimated moderate activity by 55%. Swartz cut-points were not different from the criterion measure. Hendelman cut point's underestimated light activity by 29% and overestimated light activity by 120%.

In another study investigating the accuracy of accelerometer cut-points Ham et al. (2007) assessed twelve subjects wearing an Actigraph accelerometer and Polar Vantage NV heart watch for seven consecutive days. Physical activity bouts were classified as moderate or vigorous based upon the cut-points of Freedson, Swartz and Hendelman. The physical activity bouts were also classified based upon a percent heart rate reserve (HRR). The two methods of intensity classification were then compared. A large percentage of moderate intensity physical activity classified by Freedson (78%), Swartz (88%) and Hendelman (94.7%) were associated with less than light category of the HRR (<45% HRR). Also the frequency and duration of moderate intensity physical activity was highly variable among cut-points as frequency ranged from 1.1 days per week to 7 days per week and duration ranged from 17.9 minutes per day to 139.2 minutes per day. However, the majority of the vigorous bouts classified by Freedson (75%), Swartz (37.5%) and Hendelman (100%) were associated with the vigorous category of the HRR (>60%) and had less variation in frequency (0.7-1.0 days per week) and duration (31.5-38.3 min per day) The findings of Ainsworth et al., Strath et al., Ham et al. demonstrate the limitations of cut-points in field-based studies. There are large differences in cut-points estimates of frequency, duration and intensity. The variability involved makes it difficult to accurately measure the percentage of adults meeting current physical activity recommendations. Further research is needed in order to develop more accurate cut-points to classify light, moderate and vigorous intensity.

Actical Accelerometer

One accelerometer well suited for field-based research and public health surveillance is the Actical accelerometer. The Actical is an omnidirectional accelerometer most sensitive to movement in the vertical plan. Its small size (28 x 27 x 10 mm), light weight (17 g), and ability to measure accelerations in as little as 15 second epochs continuously for up to 44 days make it ideal for field-based studies. In addition, the Actical's sensitivity (0.5-3.0 Hz) allows for measurement of both sedentary and high energy movements. Only a few studies to date have tested the validity and reliability of the Actical accelerometer to measure energy expenditure, most of which involve children. Pfeiffer et al. (2006) studied eighteen preschool children at rest, during structured activities and during unstructured activities while wearing the Actical and a portable metabolic system. Rest consisted of sitting in a reclined chair for 10 minutes while watching a cartoon. Structured activities consisted of walking and jogging for 5 minutes at 3 different speeds paced by a researcher. Unstructured activity involved 20 minutes of free play with classmates in both an indoor and outdoor setting. The Pearson correlation coefficient between VO_2 and activity counts for all activities was 0.89. The intraclass correlation coefficient between predicted VO_2 using a regression equation and actual VO_2 was 0.59. And finally, cut-points for moderate and vigorous activity were 715 and 1411 counts per 15 seconds, respectively. Corder et al. (2005) also tested the validity of the Actical for measuring energy expenditure in children through a laboratory study. Thirty-nine children completed a graded exercise test on a motorized treadmill while wearing the Actical on either their right or left hip. Oxygen uptake was obtained during the graded exercise test through a metabolic measurement system. Each child began the exercise test walking at 3.2 km/h at 0% grade and continued walking for 15 minutes as speed and grade gradually increased to 5.8 km/h at 10.2% grade. After 15 minutes, grade was decreased to 0% and subjects began running at 9 km/h, with speed increasing every minute until 12.2 km/h. Using a regression equation to predict energy expenditure, Corder et al. found the Actical alone accounted for 67% variation in energy expended during physical activity. Correlation between predicted energy expenditure and criterion measured energy expenditure for the Actical was 0.60.

In another Actical calibration study involving children, Puyua et al. (2004) examined thirty-two children between ages of 7-18 as they performed a variety of activities while wearing the Actical at their right hip. Activities included resting, playing Nintendo, using a computer, cleaning, aerobic exercise, ball toss, and treadmill walking (2.0-4.0 mph) and running (4.5-7.0 mph) for varying amounts of time. Puyua et al. validated the predicted energy expenditure by creating a regression equation using activity counts, age, sex, weight and height and compared it to four hours of direct calorimetry for each subject. Activity counts accounted for 81% of the variability in aerobic energy expenditure. Cut-points were also created by Puyau et al. as light activity was classified as 100 cpm, moderate was classified as 1500 cpm and vigorous was classified as 6500 cpm.

The Actical accelerometer has been less studied in adults. To date only three studies have attempted to measure the validity and reliability of the Actical to predict energy expenditure in adults. Klippel and Heil (2003) studied the validity of the Actical for measuring energy expenditure in twelve males and twelve females. Each subject performed nine activities, including three sitting activities (typing, hand writing, card sorting), three household activities (floor sweeping, vacuuming, dusting) and treadmill walking and jogging for 5 minutes at 67 m/min, 80.4 m/min and 120.6 m/min respectively. During each activity an Actical was worn on the subjects' non-dominant wrist and ankle, as well as their right hip and oxygen uptake was measured using a portable metabolic system. The last 2 minutes from the Actical and metabolic system were averaged for each activity and a linear regression was used to create MET prediction algorithms. Predicted METs were compared to actual METs using a Pearson product moment correlation. Correlations for the ankle $r = 0.77$, hip 0.94, and wrist $r = 0.90$ suggest the algorithms created for the Actical yielded fairly accurate prediction of METs. Using the same subjects and methodology, Heil (2006) also created ankle, hip and wrist algorithms that predict energy expenditure from activity counts. Although the regression equations showed some variation for adults ($r^2 = 0.14$- 0.85), they accurately predicted energy expenditure ($p > 0.05$).

The third adult calibration study for the Actical was conducted by Crouter and Bassett (2008). Forty-eight subjects performed routines that consisted of ten various lifestyle and sporting activities. Each activity was performed for 10 minutes, with 1-2 minutes of rest between each activity. There were three routines, each with different activities. Each routine was performed twenty times by different subjects. While the subjects were performing the routine, they wore a portable metabolic system and the Actical on their left hip. For each activity, VO_2 was converted to METs and averaged during minutes 4-9 for each activity. For the Actical, activity counts for minutes 4-9 were also averaged. Then each activity was classified as either walk/run or lifestyle activity based on the coefficient of variation ((standard deviation of four consecutive 15 sec epochs within 1 min divided by the mean) x 100). An activity with a coefficient of variation below 13% was considered walking/running, while an activity with a coefficient of variation greater than 13% was considered a lifestyle activity. Two separate regression equations were then created for each type of activity and used to predict METs. Predicted METs from the regression equation were within 0.56 METs of measured METs for all activities ($p \geq 0.05$). Based upon the early findings of Crouter et al. and Klippel and Heil, the Actical accelerometer is a fairly accurate predictor of METs in adults. However, further research is needed to validate the findings of Crouter et al. and Kilppel and Heil in order to determine the accuracy of Actical for measuring energy expenditure and exercise intensity.

Summary

Most adults in the United States are not engaging in the recommended 30 minutes of moderate physical activity five days a week or 20 minutes of vigorous physical activity three days a week needed to attain the health benefits associated with physical activity. However, most public health surveillance systems involve the use of self-reports to estimate adult physical activity levels. Evidence of the dose-response relationship between moderate physical activity and health outcomes is also based upon self-reported physical activity. Self-reports have been shown to underestimate the frequency, intensity and duration of moderate physical activity, are cognitively challenging and are prone to reporting bias. Therefore, the proposed health benefits associated with moderate physical activity, as well as the percentage of adults meeting the recommended amounts of moderate physical activity may be inaccurate. Objective monitoring of physical activity is needed to more accurately determine the appropriate physical activity dose needed to elicit the health benefits of physical activity and to determine valid statistics of adults meeting physical activity recommendations. Accelerometers can provide an objective way of monitoring frequency, intensity, duration and energy expenditure. However, to attain these measures each accelerometer most undergo field and laboratory calibration. One accelerometer in need of calibration among adults is the Actical accelerometer. To date three Actical calibration studies have been conducted on adults. However, the regression equations used to estimate intensity level have not been adequately validated and were developed using METs as means for classifying intensity. This study will seek to create adults cut-points for the Actical accelerometer using a percentage of VO_2max in order to classify intensity.

CHAPTER III

METHODS

Subjects

Twenty-five healthy subjects from the University of North Carolina between the ages of 18-35 were recruited for this study. No previous exercise training was required for inclusion in this study; however, subjects must have had the ability to walk and run on a motorized treadmill without assistance. Subjects were excluded if there are any signs or symptoms of cardiovascular, pulmonary or metabolic disease. Subjects were also excluded if there was any known muscoskeletal injury that prevented them from walking and running at various speeds. All testing procedures and potential risks were explained to the subject and informed consent documented prior to participation in this study.

Instrumentation

Body mass was measured with the participant dressed in shorts, t-shirt and socks to the nearest 0.1 kilogram using a mechanical scale (Detecto, Webb City, MO). Height was measured without shoes to the nearest 0.01 centimeters using a portable stadiometer (Perspectives Enterprises, Portage, MI). Blood Pressure was measured by auscultation using a stethoscope and mercury sphygmomanometer (American Diagnostic Corporation, Hauppauge, NY). Subjects were outfitted with a Polar heart rate transmitter (Polar Electro, Lake Success, NY) worn snuggly around the chest, centered just below the pectoral muscles. Subjects were also be outfitted with an Actical accelerometer (Mini Mitter Company Inc, Bend, OR) attached to a belt at the right anterior axillary line. The Actical accelerometer is a light weight (17 g), omni-directional accelerometer that measures accelerations from 0.5-2.0 G. The Actical accelerometer was initialized to record accelerations at one minute epochs. The submaximal graded exercise test was then conducted on a Quinton Treadmill (Cardiac Science Corporation, Bothell, WA). The treadmill was calibrated for speed and grade according to specifications provided by the manufacturer. Oxygen uptake was measured breath-by-breath during exercise testing using the Parvo Medics TrueMax 2400 Metabolic Measurement System (Parvo Medics, Sandy, UT), which was as per manufacturer instructions. During exercise testing, rate of perceived exertion (RPE) was obtained using Borg's 6-20 scale (Borg 1970).

Procedures

Upon arrival to the Applied Physiology Laboratory, subjects were given a detailed description of the exercise protocol, instructed of the purpose and risks involved, and signed an informed consent. Once consent was documented, subjects completed a medical history questionnaire. If the subjects met the inclusion criteria, baseline procedures were conducted. Body mass, height, resting blood pressure and resting heart rate were assessed. Resting blood pressure and resting heart rate were obtained following five minutes of rest in the supine position. Subjects' maximal heart rate was calculated using the age-predicted formula 209 – 0.73 –age (Robergs and Landwehr 2002). Resting heart rate was used to calculate 75% of the subjects' heart rate reserve (HRR) using the Karvonen formula (%HR = [HRmax – HRrest] x 75% + HRrest) (Karvonen et al. 1957). Following baseline measures, subjects were outfitted with the Actical accelerometer, a one-way mouthpiece apparatus and nose clips. The mouthpiece was connected to the Parvo Medics TrueMax 2400 Metabolic Measurement System to directly measure inspired and expired air in order to calculate VO_2. Once all equipment was attached to the subject, the treadmill was powered on while the subject straddled the treadmill belt. When appropriate speed had been obtained, the subject was instructed to begin walking. The graded exercise tests consisted of four minute stages, with speed increasing 1.0 mph at the end of each stage (Table 1).

VO_2 was measured continuously throughout the duration of the exercise test. Heart rate was also monitored continuously during exercise testing and recorded along with RPE at the end of each stage. Subjects began walking at 2.0 mph and continued walking then running until the subject reached 75% of their HRR. Upon reaching 75% of their HRR, subjects continued exercising until the stage was completed. Once the exercise test had been terminated, treadmill speed was decreased to 2.0 mph and subjects continued walking until their heart rate dropped below 110 beats per minute and their blood pressure had stabilized.

Table 1. Exercise test protocol.

Stage	**Speed (mph)**	**Time (minutes)**
1	2.0	0 – 4
2	3.0	4 – 8
3	4.0	8 - 12
4	5.0	12 - 16
5	6.0	16 -20
6	7.0	20 - 24
7	8.0	24 - 28

Data Reduction

All oxygen uptake and Actical data was downloaded onto a laptop computer and used for data analysis. Only VO_2 data obtained during the last two minutes of each completed stage was used in data analysis, as it was assumed steady state has been achieved. Only accelerometer data obtained during the second and third minutes of each stage were used in data analysis. Accelerometer data from the first and last minutes of each stage were excluded due to inaccurate activity counts obtained as the subject adjusted to speed changes and the inability to accurately coordinate VO_2 and accelerometer data. Mean activity counts using 2nd and 3rd minutes were calculated for each subject at all completed stages.

Data Analysis

Intensity thresholds were created by first calculating each subject's VO_2max. VO_2max was predicted by calculating the slope (b) using the equation $b = (SM_2 - SM_1)/(HR_2 - HR_1)$, with SM as the submaximal workloads (expressed as VO_2) and HR as the heart rates obtained during the final two stages of exercise testing. Using the slope, VO_2 max was then predicted using the ACSM equation (American College of Sports Medicine 2006): $VO_2\ max = SM_2 + b\ (HR\ max - HR_2)$. Using each subjects estimated VO_2 max, 40% and 65% VO_2 max were calculated and used as the definitions for moderate and vigorous intensity.

In order to calculate VO_2 based cut-points for the Actical accelerometer, individual regression equations were first created to predict VO_2 (mL/kg/min) for any speeds not reached by a subject up to 8.0 mph. Speed was used as the independent variable and VO_2 (mL/kg/min) as the dependent variable. Then, using the predicted VO_2 values, activity counts were predicted using individual regression equations for each uncompleted speed. For this regression equation, VO_2 was used as the independent variable and activity counts as the dependent variable. Once VO_2 (mL/kg/min) and activity counts were predicted for all speeds up to 8.0 mph, a regression equation was created for each individual subject using VO_2 as the independent variable and activity counts as the dependent variable. Skinner and McLellan (1980) define moderate and vigorous physical activity as 40 and 65% of VO_2max. Therefore, each regression equation was used to predict activity counts at 40 and 65% VO_2max. The individual activity counts at 40 and 65% VO_2max were averaged for all subjects and used to create cut-points that correspond to light-to-moderate (40% VO_2max) and moderate-to-vigorous (65% VO_2max) physical activity.

MET based cut-points were developed by first converting all VO_2 values (mL/kg/min) into METS. VO_2 values were converted into METS by each dividing each VO_2 value by 3.5 mL/kg/min. Individual regression equations were then created for each subject using METS as the independent variable and activity counts as the dependent variable. The standard MET definition of moderate and vigorous physical activity is 3 and 6 METS (Crouter et al. 2006). Therefore, each regression equation was used to predict activity counts at 3 and 6 METS. The individual activity counts at 3 and 6 METS were averaged and used to create cut-points that correspond to light-to-moderate (3 METS) and moderate-to-vigorous (6 METS) physical activity.

Individual VO_2 based cut-points and individual MET based cut-points were compared using a two-way independent ANOVA (method x intensity). Post hoc, independent samples t-test was then used to test for differences between light to moderate VO_2 based cut-points and light to moderate MET based cut-points. An independent samples t-test was also used to test for differences between moderate to vigorous VO_2 based cut-points and MET based cut-points. To determine the accuracy of each cut-point, residuals were calculated by subtracting each individual cut-point by the mean cut-point. Bland-Altman plots using the residual scores were than created to test how accurately the mean cut-points classified light to moderate and moderate to vigorous intensity. Accurate cut-points will display residuals closer to zero. Residual points below zero indicate an overestimation. Residual points above zero indicate an underestimation. All statistical procedures were conducted using the Statistical Package for the Social Sciences version 15.0 (SPSS, Chicago, IL). The alpha level was set at $p < 0.05$ for all statistical procedures.

CHAPTER IV

RESULTS

Subject Characteristics

Twenty five subjects (13 males, 12 females) between the ages of 18 -29 completed the exercise protocol. Mean physical characteristics and estimated VO_2max are presented in Table 2. Males and females significantly differed in body mass ($p = 0.006$) and height ($p = 0.002$) but were similar in body mass index (BMI). All subsequent analyses were based on all participants.

Table 2. Mean ± standard deviation (SD) physical characteristics of the twenty five subjects presented by sex.

	Male	**Female**	**All Participants**
N	13	12	25
Age (years)	23.2 ± 3.7	24.8 ± 3.3	24.0 ± 3.5
Body Mass (kg)	76.0 ± 11.1*	65.1 ± 6.0*	70.8 ± 10.4
Height (cm)	178.3 ± 8.5*	168.6 ± 4.9*	173.6 ± 8.5
BMI (kg/m²)	23.9 ± 3.3	23.0 ± 2.5	23.5 ± 3.0
Estimated VO_2max (mL/kg/min)	51.2 ± 14.3*	38.8 ± 8.6*	45.8± 13.5

*$p < 0.05$

Activity Counts, VO_2, and METS

The duration of each exercise test ranged from 16 – 32 minutes, with subjects reaching 75% HRR between speeds of 5.0 and 9.0 mph. Only one subject completed a stage of 9.0 mph. Therefore, only data obtained during speeds of 2.0 – 8.0 mph were included for analysis. The mean and standard deviation of activity counts, VO_2 (mL/kg/min) and METS at each speed are shown in Table 3. Activity counts per minute (cpm), VO_2 and METS each increased with speed.

Table 3. Mean (± SD) Actical counts (cpm), VO_2 (mL/kg/min) and METS for all speeds (mph).

Speed (mph)	**Activity Counts (cpm)**	**VO_2 (mL/kg/min)**	**METS**
2.0	1182 ± 299	9.4 ± 1.3	2.7 ± 0.4
3.0	2418 ± 416	11.9 ± 1.4	3.4 ± 0.4
4.0	4217 ± 861	16.9 ± 2.1	4.8 ± 0.6
5.0	9047 ± 2171	26.7 ± 4.3	7.6 ± 1.2
6.0	11533 ± 1555	32.5 ± 4.2	9.3 ± 1.2
7.0	13260 ± 1952	37.7 ± 5.4	10.8 ± 1.6
8.0	15918 ± 2664	44.0 ± 6.2	12.6 ± 1.8

Cut-points

The results of two separate linear regressions show VO_2 and METS each accounted for 81.3% of the variance of all activity counts, with a standard error of the estimate of 2394.4 and 2391.1 cpm respectively. Individual regression equations for each subject were used to predict activity counts at 40% and 65% VO_2 max. Individual regression equations for each subject were also used to predict activity counts at 3 and 6 METS. The mean activity counts at 40 and 65% VO_2 max and the mean activity counts at 3 and 6 METS were then used to create cut-points. Light, moderate and vigorous cut-points are displayed in Table 4. The results of a two-way ANOVA using method (VO_2 & METS) and intensity (light-to-moderate and moderate-to-vigorous) as independent variables and individual cut-points as the dependent variable reveal that cut-points significantly differed by the intensity level ($p = 0.0001$) and the method used to develop the cut-points ($p = 0.0001$). Subsequent independent t-tests comparing individual MET cut-points to VO_2 cut-points show that light-to-moderate and moderate-to-vigorous VO_2 cut-points are significantly greater than light-to-moderate and moderate-to-vigorous MET cut-points ($p = 0.003$, $p = 0.029$ respectively).

Table 4. Comparison of light to moderate and moderate to vigorous cut-points derived using a percentage of VO_2 versus light to moderate and moderate to vigorous cut-points derived using METS.

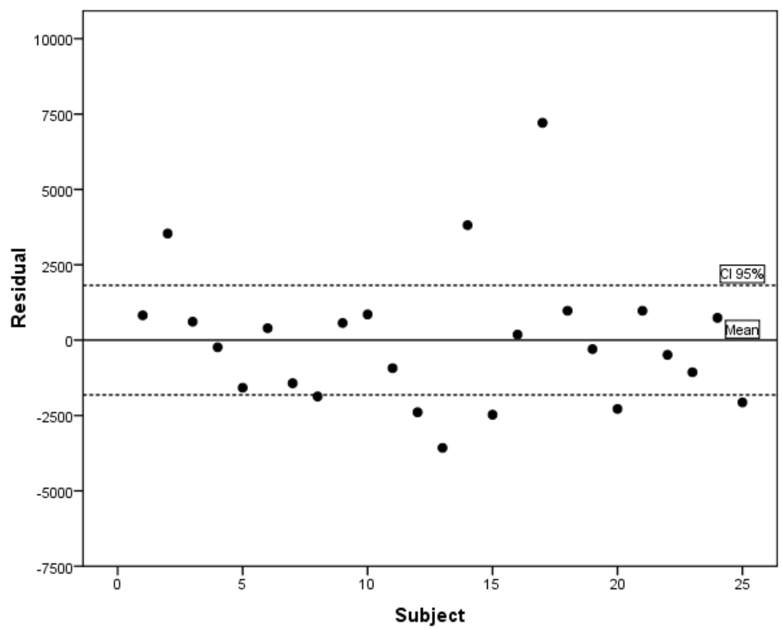
	Cut-point (cpm) derived using percent VO_2 max		*Cut-point (cpm) derived using METs*	
Light-Moderate	40%VO_2 max	4952	3 METS	1782
Moderate - Vigorous	65%VO_2 max	9714	6 METS	6464

Individual cut-points versus mean cut-points

The difference between each individual VO_2 cut-point and the mean VO_2 cut-points are expressed as residuals and are depicted in Figure 1. The residual for cut-points at 40% VO_2 max had a standard deviation of 4637 cpm. The residual for cut-points at 65% VO_2 max had a standard deviation of 3622 cpm. Bland-Altman plots of the 40 and 65% VO_2 cut-points shows that 68% of the individual moderate cut-points fall within the 95% confidence interval (CI) (1818 cpm) and 52% of the individual vigorous cut-points fall within the 95% CI (1420 cpm). The difference between each individual MET cut-point and the mean MET cut-points are depicted in Figure 2. The residual for cut-points at 3 METS had a standard deviation of 837 cpm. The residual for cut-points at 6 METS had a standard deviation of 1652 cpm. Bland-Altman analysis of 3 and 6 MET cut-points reveals that 40% of the light-to-moderate and 36% of the moderate-to-vigorous individual cut-points fall within the 95% CI (328 and 647 cpm respectively). Comparison of Bland-Altman plots of VO_2 cut-points and MET cut-points shows greater residuals exist among VO_2 cut-points, but a larger percentage of individual cut-points fall within the 95% CI.

Figure 1. Bland-Altman plot depicting residuals between individual cut-points and the mean cut-point at 40% VO_2max (A) and 65% VO_2max (B).

A



B

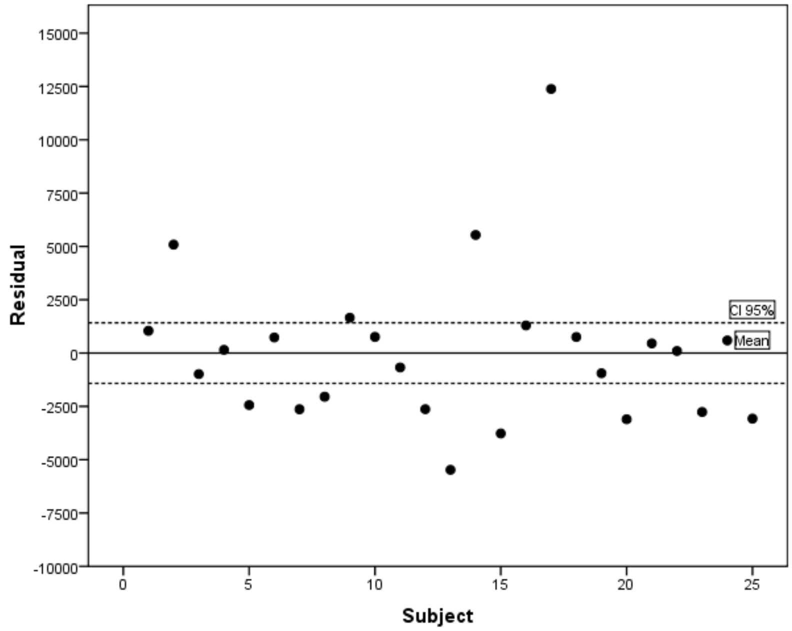
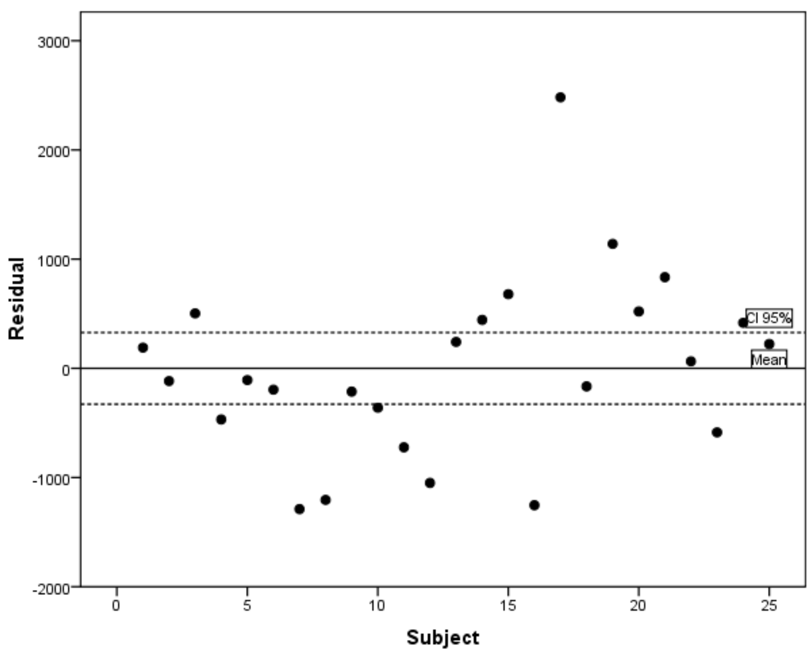
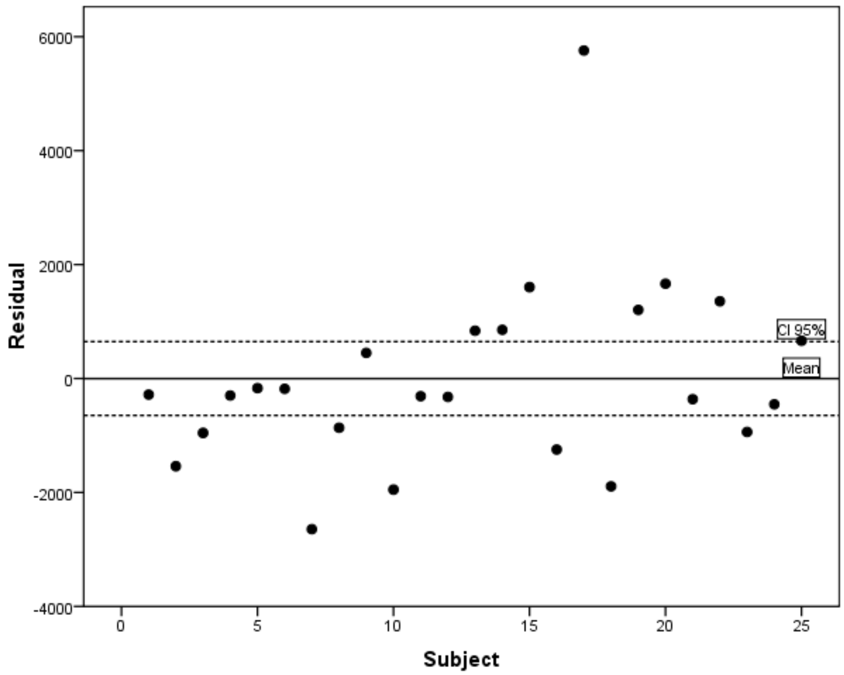


Figure 2. Bland-Altman plot depicting residuals between individual cut-points and the mean cut-point at 3 METS (A) and 6 METS (B).

A



B


6000
4000
2000
0
-2000
-4000
Residual
0
5
10
15
20
25
Subject
CI 95%
Mean

CHAPTER V

DISCUSSION

In the current study, the Actical accelerometer was calibrated in adults under laboratory conditions with the purpose of developing cut-points that correspond to light-to-moderate and moderate-to-vigorous intensity physical activity. All subjects performed a progressive submaximal exercise test on a treadmill while wearing the Actical and having oxygen uptake. To date this is the first Actical calibration study involving adults that uses a percentage of VO_2max as means for classifying intensity. VO_2 was shown to be a strong predictor of Actical activity counts during treadmill walking and running ($R^2 = 0.813$, SEE = 2394.4 cpm). The results of this study suggest that activity producing between 4952 Actical cpm was considered the light-to-moderate cut-point (40% VO_2max) and 9714 cpm was determined to be the moderate-to-vigorous cut-point (65% VO_2max).

Comparison to Previous Research

Previous calibration studies of the Actical accelerometer have been conducted on both children and adults under field and laboratory settings. The results of three previous Actical calibration studies in adults are not comparable to the results of the current study because they did not determine cut-points, only developing equations for predicting energy expenditure. Klippel and Heil (2003) created regression equations for ankle, hip and wrist sites that predict METS from Actical activity counts. Using the same subjects and methodology, Heil (2006) also developed ankle, hip, and wrist regression equations to predict energy expenditure from Actical activity counts. Crouter and Bassett (2008) developed a 2-regression model that relates activity counts to METS. In the current study, no one single regression equation was developed. Rather, individual regression equations were created to predict activity counts from VO_2 in order to create cut-points.

Cut-points for the Actical accelerometer were only developed in calibration studies involving children, making it difficult to compare findings from this current study. Puyau et al. (2004) created cut-points for light (100 cpm), moderate (1500 cpm) and vigorous (6500 cpm) physical activity in children and adolescents (7 -18 years old). Pfeiffer et al. (2006) developed moderate (2860 cpm) and vigorous (5644 cpm) cut-points in preschool children (3-5 years old). Although both studies involved structured activities in laboratory and field settings, the nearly 1000 count difference between preschool and adolescent cut-points indicates the variation in cut-points between specific populations. This large variation between preschool children cut-points and adolescent cut-points may explain why cut-points from the current study are much greater than those developed by Puyau and Pfeiffer. Gait differences between young children and adolescents, as well gait differences between children and adults make it difficult to apply cut-points across age groups. Greater height is associated with greater stride length and lower stride frequency (MacDougall et al. 1983), which will potentially cause activity counts to be lower as we age from childhood to adulthood. Therefore, it is necessary to develop cut-points for specific populations and specific age groups as different populations will yield different cut-points.

VO_2 based cut-points versus MET based cut-points

Calibration studies involving the Actical accelerometer (Crouter et al. 2006, Crouter and Bassett 2008) as well as calibration studies of other accelerometers (Freedson et al. 1998, Nichols et al. 1999, Hendelman et al. 2000, Swartz et al. 2000) most often use METS to determine cut-points. In the current study we sought to compare two different methods for creating cut-points. Activity counts at 40% and 65% VO_2 max and activity counts at 3 and 6 METS were used to create moderate and vigorous cut-points. Comparison of VO_2 cut-points to MET cut-points show light-to-moderate (4952 cpm) and moderate-to-vigorous (9714 cpm) VO_2 cut-points were significantly greater than light-to-moderate (1782 cpm) and moderate-to-vigorous (6464 cpm) MET cut-points. Conversion of VO_2 values at 40 and 65% VO_2max into METS suggests that the differences in cut-points can be attributed to the underestimation of intensity using the MET classifications. Twenty-four out of twenty-five VO_2 values at 40% VO_2max, when converted to METS, were above 3 METS, which is the definition of moderate intensity, with a mean of 5.2 ± 1.5 METS. Twenty-two out of twenty-five VO_2 values at 65% VO_2max, when converted to METS, were above 6 METS, which is the definition of vigorous intensity, with a mean of 8.5 ± 2.5 METS. This suggests that the standard 3 and 6 MET definitions of moderate and vigorous intensity may not represent moderate and vigorous intensities for young adults. This also suggests MET definitions of moderate and vigorous intensity may also be too liberal. Thus, the use METS as means for defining intensity level may results in significantly lower cut-points and misclassification of physical activity intensity.

MET Value Comparison

The Compendium of Physical Activities (Ainsworth et al. 2000) is one of the most commonly used methods for classifying the intensities of physical activity in adults who are without disabilities. The Compendium provides a coding scheme that is linked to an estimated MET level for a large variety of physical activities. Activities range from sleeping (0.9 METS) to running at 10.9 mph (18 METS). The results of the current study are comparable to Compendium MET listings for walking and running. Mean MET values for walking at 2.0, 3.0 and 4.0 mph in the current study were 2.7, 3.4, and 4.8 METS respectively. This is similar to Compendium MET values of 2.5, 3.3, and 5 METS for similar walking speeds. Mean MET values for running at 5.0, 6.0, and 7.0 in the current study were 7.6, 9.3, and 10.8 METS respectively. These values are somewhat comparable to Compendium MET values of 8, 10, and 11.5, for similar speeds. The greatest difference occurred at 8.0 mph, as the Compendium MET value of 13.5 overestimated energy expenditure when compared to the MET value of 12.6 METS in the current study.

Cut-point Variability

Although cut-points developed using a percentage of VO_2max may be more reflective of an individual's true intensity level, the variability of VO_2 cut-points should be considered when being used in group classification. In the current study, cut-points were created for each individual subject and were then averaged to create mean cut-points. The standard deviations of the mean cut-points at 40% VO_2max and 65% VO_2max were 2312 and 3622 cpm, respectively. Bland-Altman plots of the residuals show that 32% of the moderate and 48% of the vigorous individual cut-points did not fall into the 95% CI. The large standard deviation and Bland-Altman plots show the high variability of the VO_2 cut-points.

Uncontrolled factors that may account for the high variability of the VO_2 cut-points include leg length and stride frequency. Leg length alters both stride frequency and stride length, as a person who has longer legs will take longer and fewer strides. Therefore, a person who takes fewer strides will produce fewer activity counts. The affect of stride frequency on activity counts was reported by Brage et al. (2003) in a study of the CSA accelerometer. Brage et al. reported stride frequency accounted for 11-40% of the variance in CSA output. Another factor that may account for the high variability in VO_2 cut-points is the inter-individual difference in VO_2 values at 40 and 65% VO_2max. VO_2 values at 40%VO_2max ranged from 9.1 to 32.5 mL/kg/min and had a standard deviation of 5.4 mL/kg/min. VO_2 values at 65% VO_2max ranged from 14.9 to 52.8 mL/kg/min and had a standard deviation of 8.8 mL/kg/min. Due to the high variability of VO_2 at 40 and 65% of capacity, a cut-point range may be used to classify intensity rather than a single cut-point. The high variability also suggests that to obtain accurate estimates of moderate and vigorous physical activity, individual calibration may be needed. However, individual calibration may not be feasible in studies containing large sample sizes.

Applicability to Field Setting

Caution should be taken when applying the VO_2 cut-points from the current study to Actical activity counts obtained in field settings. Calibration studies of other accelerometers have shown that data obtained under laboratory conditions cannot be applied to data obtained from field conditions. In a study of the CSA accelerometer Nichols et al. (2000) reported CSA activity counts produced during treadmill walking and running significantly differed from CSA activity counts produced during outdoor walking and running. Similarly, Morgan et al. (1999) reported laboratory developed cut-points for the Tritrac accelerometer misclassified 33% of light and 20% of moderate activities in field settings. The differences between accelerometer counts in laboratory settings versus level field settings may be biomechanical, as the literature shows stride frequency and length change when running on a treadmill (Elliot and Blanksby 1976). This may explain why Actical counts obtained during treadmill walking of the current study slightly differed from walking counts obtained under level field conditions. Holleman et al. (2008) created Actical cut-points at various walking speeds by assessing thirty-three males during a home based walking program. Cut-points at 2.0 and 3.0 mph were 1750 and 2750 cpm, respectively. Mean activity counts from treadmill walking at 2.0 and 3.0 mph from the current study were slightly different, as counts were 1182 and 2417 cpm respectively. To date only one calibration study of the Actical accelerometer has cross-validated laboratory cut-points to cut-points in a field setting. Pfeiffer reported that in children although laboratory based regression equations predicting VO_2 from activity counts underestimated VO_2 values obtained in a field setting, the agreement between measured and predicted VO_2 was acceptable. Further research is needed however to cross-validate Actical cut-points from the current study in a field setting.

Limitations

In addition to the lack of generalizability of the developed cut-points to activities performed in a field setting, there are other limitations in this study. One limitation is that the cut-points were created using only young, healthy adults. Differences in accelerometer counts have been reported between younger and older adults (Nichols et al. 1992). Therefore, cut-points from the current study can only be applied to studies involving young, healthy adults. Another limitation of this study is the small sample size. Although the number subjects used in the current study are comparable to other accelerometer calibration studies (Hendleman et al. 2000, Puyau et al. 2002, Pfeiffer et al. 2006), the small sample size limits the generalizability and power of this study.

Conclusion

Adult cut-points for the Actical accelerometer based upon a percentage of VO_2max were as follows: light-to-moderate was 4952 cpm and moderate-to-vigorous was 9714 cpm. Compared to MET based cut-points, VO_2 cut-points were significantly greater. This may be due to the fact that MET definitions of moderate and vigorous physical activity over predicted the exercise intensities. Although VO_2 based cut-points may more accurately reflect light, moderate, and vigorous intensity, their high variability suggests creating one single VO_2 based cut-point will cause misclassification of physical activity levels.

Recommendations for future research

Further research of the Actical accelerometer in adults is needed in order to validate cut-points from the current study. Attempts should be made to include adults across all age groups to determine if the results are generalizable to all adult populations. Validation of adult cut-points should be made in both field and laboratory settings. To date, only one Actical calibration study has cross-validated cut-points developed under laboratory conditions to field settings and that one study involved children(Pfeiffer et al. 2006) Therefore, it is recommended that adult Actical cut-points be cross-validated in a field setting to determine the generalizability of adult cut-points to free-living conditions. Additional research is also needed to verify the use of percentage of VO_2max as means for classifying intensity and developing cut-points. Most accelerometer calibration studies develop cut-points based upon METS. The current study suggests a significant difference exists between MET based cut-points and VO_2 based cut-points. Researchers should attempt to verify the differences seen between MET based cut-points and VO_2 cut-points.

APPENDIX A

Informed Consent

University of North Carolina-Chapel Hill

Consent to Participate in a Research Study

Adult Subjects

Biomedical Form

IRB Study #_09-0011____________________

Consent Form Version Date: _1/20/09______

Title of Study: Calibration of the Actical Accelerometer in Adults

Principal Investigator: Jason Diaz

UNC-Chapel Hill Department: Exercise & Sports Science

UNC-Chapel Hill Phone number: 732-586-2899

Email Address: diazj2@email.unc.edu

Faculty Advisor: Dr. Robert McMurray

Funding Source and/or Sponsor: None

Study Contact telephone number: 732-586-2899

Study Contact email: diazj2@email.unc.edu

What are some general things you should know about research studies?

You are being asked to take part in a research study. To join the study is voluntary.

You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

Research has shown that moderate to vigorous activity has the greatest impact on health. Thus, it is important to accurately assess physical activity to determine if an adult meets the recommended amounts of moderate to vigorous activity. The Actical accelerometer is a device used to objectively measure physical activity by recording accelerations in various planes. Accelerations are recorded as activity counts and can be used to estimate the intensity of physical activity. However, the relationship between Actical output and exercise intensity is not known. Therefore, the purpose of this research study is to develop cut points (thresholds) for the Actical accelerometer that correspond to light, moderate and vigorous intensity.

You are being asked to be in the study because you are between the ages of 18-35, are in good health and have the ability to walk and run on a motorized treadmill.

Are there any reasons you should not be in this study?

You should not be in this study if you are currently pregnant or have a history of heart disease, uncontrolled diabetes, hypertension, pulmonary disease, severe arthritis, extreme overweight, major orthopedic problems, or any other condition that could cause a problem during exercise or place you at risk during exercise.

How many people will take part in this study?

If you decide to be in this study, you will be one of approximately 24 people in this research study.

How long will your part in this study last?

Prior to exercise testing you will complete a medical history exam and undergo some baseline measures which will last approximately 20 minutes. Following the baseline measures you will participate in one exercise testing lasting approximately 20-25 minutes. The total duration of all testing procedures will be under one hour.

<u>What will happen if you take part in the study?</u>

1. Upon arrival, you will be given a medical history questionnaire to complete.
2. If you meet the inclusion criteria, your height and weight will be measured and recorded.
3. You will then be outfitted with a heart rate monitor and sit down for five minutes. Following five minutes of rest, your resting heart rate will be recorded and used to calculate 75% of your heart rate reserve which will be used to determine how hard you will exercise during the experimental portion of the session. Also your resting blood pressure will be measured and recorded following the rest period.
4. You will then be instructed to place the accelerometer belt around your waist, with the accelerometer positioned on your right hip.
5. You will then straddle the treadmill belt and insert a mouthpiece and put on a nose clip, which will be used to measure oxygen uptake.
6. The treadmill belt will be turned on and set at 2.0 mph with a level grade. An instruction will be given to you to begin walking once the appropriate treadmill speed has been reached.
7. You will walk at 2.0 mph for four minutes. At the end of the stage, heart rate and rate of perceived exertion will be measured and recorded.
8. Speed will increase 1.0 mph at the end of every four minute stage until you have reached approximately 75% of your maximal exercise ability. Heart rate and your perceived exertion will be measured and recorded at the end of each stage.
9. Upon test termination you will remain on the treadmill and cool down by walking at a speed of 2.0 mph while heart rate and blood pressure will be monitored every 2 minutes. You will continue to walk until your heart rate drops below 110 beats per minute and your blood pressure has stabilized.

<u>What are the possible benefits from being in this study?</u>

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

<u>What are the possible risks or discomforts involved with being in this study?</u>

Although there is an inherent risk involved with all exercise testing, this study poses a minimal health threats. You will be performing a submaximal test which has a predetermined end point (75% of your maximal capacity) and does not require you to exercise until exhaustion. You may request to stop at any time.

During exercise testing, you may experience fatigue or lightheadedness. In very rare instances, exercise has resulted in heart attack, stroke or sudden death heart attack, stroke or sudden death. Every effort will be made to minimize these risks. Emergency procedures are posted throughout the laboratory, an AED is on hand and all staff is certified in CPR and first aid. Exercise testing will be conducted at the Applied Physiology Laboratory on the campus of the University of North Carolina in Chapel Hill. The Applied Physiology lab stores a very small amount of radioactive materials, which are in compliance with the University of North Carolina's Office of

Environmental, Health & Safety regulations. The small amounts of radioactive material are located in a separate area of the laboratory from which exercise testing will conducted. Therefore, the radioactive material will not present any health threat to you.

In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

What if we learn about new findings or information during the study?

You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?

All subjects will be identified by a randomly assigned subject number that will be used throughout the study. To ensure all data is kept confidential, all electronic files will be saved in a password protected document on a password protected computer and locked in file cabinet located in the graduate advisor's office when not in use. All other subject data will be stored within a locked file cabinet in the Applied Physiology Laboratory. Only myself and my graduate advisor will have access to this information.

No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?

It will not cost you anything to take part in this study.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?

Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Title of Study: Calibration of the Actical Accelerometer in Adults

Principal Investigator: Jason Diaz

<u>Subject's Agreement:</u>

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

____ ____________________

Signature of Research Subject Date

____

Printed Name of Research Subject

____ ____________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

APPENDIX B

Recruitment Email

Free Fitness Test

My name is Jason Diaz and I am a graduate student in the Department of Exercise and Sports Science at the University of North Carolina. I am currently conducting a research project which involves the calibration of the Actical accelerometer, a small device worn around the waist, which is commonly used to measure physical activity. I am looking for volunteers who would be willing to participate in a research project in which the participant will perform an exercise test while wearing the Actical accelerometer. The exercise testing will consist of walking and running on a treadmill for approximately 20-25 minutes. From this exercise test your maximal oxygen uptake or fitness level can be estimated. In order to be included for this study you must be between the ages of 18-35, be in good health and have the ability to walk and run on a motorized treadmill without assistance. If you are interested in participating in this research project or if you have any questions, please contact me at diazj2@email.unc.edu.

APPENDIX C

Data Collection Sheet

Subject: _________________________________ Date: ________________

Age: _______________ Height: ___________ cm Mass: ______________ kg

Predicted Maximal HR 208.754-0.734(age): ______________

75% Predicted HR: ____________

Resting HR: _______________

Resting BP: ________________

___ Treadmill experience or practice

___ Actical Initialized and belted on the right hip

Speed (mph)	Time Start	Duration	Heart Rate*	RPE**
2	________	4 min	________	________
3	________	4 min	________	________
4	________	4 min	________	________
5	________	4 min	________	________
6	________	4 min	________	________
7	________	4 min	________	________
8	________	4 min	________	________

Finish Time ________

* Heart rate taken the last 10 second of each minute and only the 4^{th} min recorded.

** RPE taken in the last 10 second of each minute and only the 4^{th} min recorded.

Exercise is stopped if RPE exceeds 16 on the 6 to 20 scale.

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