THE INFLUENCE OF BOUT INTERRUPTIONS ON MEASURED AND PREDICTED PHYSICAL ACTIVITY DURING TREADMILL WALKING AND RUNNING

by

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ABSTRACT

The importance of daily physical activity (PA) has been established as a means of decreasing risk for chronic diseases. However, the presence of bout interruptions ((BI), defined as a brief pause (< 2 min) PA), can complicate measures of PA. This study was designed to evaluate the influence of different BI rules on PA during treadmill locomotion. Fifteen runners (6 women, 9 men) completed a series of walking (53.6, 107.2 m/min) and running (160.8 m/min) trials while using a metabolic measurement system to measure actual activity energy expenditure (AEE_A) and four activity monitors to measure predicted AEE (AEE_P). Treadmill speeds were selected to elicit light (L), moderate (M), and vigorous (V) PA intensities. Both AEE_A and AEE_P, were calculated as the sum within and between the start and end of each defined trial using 3 BI rules: 1) without an allowance for a BI (BI0), 2) or a 1-min BI allowance (BI1), 3) or a 2-min BI allowance (BI2). T_A and T_P were defined as the time spent at or above a moderate intensity during each PA bout for BI0, BI1, and BI2. Values of AEE_A and AEE_P for each BI definition and PA intensity were compared within intensities categories using a 2-factor RMANOVA, while data for all three PA intensities were evaluated simultaneously using a RMANOVA. Similarly, values of T_A and T_P for each BI definition were compared using the same multivariate RMANOVA model. Mean AEE_A and AEE_P for BI0 were significantly lower than those for BI1 and for BI2 at all PA intensities ($p<0.05$). When expressed as a percentage, the increase in AEE_A and AEE_P between BI0 and BI1, or BI1 and BI2, was 0.3-3.9% and between 5.5-11.0% for T_A and T_P across all intensities. Allowing for 1- or 2-min BIs within a PA bout significantly influences AEE and time during locomotion. These results suggest that rules for the number of BIs allowed should be established since an increase in BIs will cause PA outcome variables to become more dependent on the BIs than the PA itself.

CHAPTER ONE

INTRODUCTION

Measurement of Physical Activity

Obesity, diabetes, and cardiovascular disease have high prevalence rates in the United States (Warburton, Nicol & Bredin, 2006). Since the 1990s, the occurrence of these diseases has doubled and thus been recognized as a significant public health issue (Weinstein & Sesso, 2006). However, lifestyle modifications, such as diet and exercise, can decrease risk for the development of these diseases. For example, an increase in physical activity is one lifestyle modification that has been shown to decrease the risk of mortality from chronic diseases (Warburton et al., 2006; Ryan, Grant, Tigbe & Granat, 2006; Leonard, 2001).

According to the United States Surgeon General, physical activity refers to any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure (EE) above the basal level (U.S. Department of Health and Human Services, 1996). Although the positive association between physical activity and positive health benefits has been well established (Warburton et al., 2006; Ryan et al., 2006; Leonard, 2001), quantifying physical activity proves to be a difficult task. Defining the quality of physical activity includes four domains: 1) frequency, or how often an activity is completed, usually reported as a weekly total and is easily measured by documenting each bout of activity in a physical activity log; 2) duration, or the total time spent engaged in an activity, typically reported as hour or minute time-series data; 3) mode, or the chosen type of activity; 4) intensity, or the degree of exertion of a particular activity. Intensity is more difficult to quantify, especially for activities of daily living (ADL) given that most of the traditional methods of measuring EE (e.g., questionnaires, activity diaries, and interview-based recalls) are influenced by self-reporting errors. Alternative methods to self-reporting, such as heart rate monitors and pedometers, can also erroneously estimate EE of ADLs (Laporte et al., 1985; Leenders, Sherman, & Nagaraja, 2000). As technology has improved, electronic measures of physical activity have improved as well by becoming smaller, less invasive, and capable of storing more data.

Acceleration-based activity monitors are small devices that measure accelerations caused by movement in one, two, or three dimensions, and thus are capable of measuring EE in ADLs. Activity monitors are typically created around a piezoelectric sensor that measures accelerations when a seismic mass deforms the piezoelectric element during an acceleration (Chen & Bassett, 2005). The deformation of the piezoelectric element is recorded and stored as a “raw count”, which is then transformed through an algorithm to yield physical activity counts for a given time or epoch length. These physical activity counts can be used to estimate EE spent at different intensity levels, which is important given that the Surgeon General’s guidelines for physical activity are based on duration and intensity. Thus, acceleration-based activity monitors can be used to determine if the duration and intensity guidelines for physical activity are being met.

While bouts of moderate intensity can be distinguished through examining raw activity monitor output, difficulties exist when interpreting individual bouts. For example, since an activity monitor measures acceleration, the raw output records zeros during pauses in physical activity. For instance, if a jogger stops at a crosswalk, the activity monitor will record a count of zero while the individual is waiting to cross the street. The interruption presents a problem when identifying bouts of physical activity in the raw data because, according to the Surgeon General, a bout of physical activity must be at least 8-10 minutes to be counted toward the goal of 30 minutes of moderate intensity. Thus, if an individual has to stop multiple times during a single physical activity bout, the raw output will show multiple short bursts of physical activity rather than a single longer continuous bout. These interruptions, referred to as bout interruptions, complicate accurate measurement of physical activity outcome variables with activity monitors (Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005). To resolve this problem, it is necessary to utilize an algorithm that accurately accounts for bout interruptions. According to Ward et al. (2005), when physical activity data are analyzed in bouts it is recommended that researchers use algorithms for bout analysis that allow for 1- or 2-min interruptions anywhere in the bout. When no interruption in bouts is allowed, the number and duration of moderate to vigorous physical activity bouts will decrease. This adjusted algorithm should result in a more accurate measure of EE and the ability to identify bouts of moderate intensity physical activity.

Statement of the Problem

The purpose of this study was to compare predicted EE from an activity monitor before and after applying bout interruption (BI) rules with actual EE for light, moderate, and vigorous intensity treadmill walking and running. The secondary purpose evaluated the influence of the same BI rules on actual and predicted measures of time (T) spent at or above a moderate intensity treadmill walking and running. In addition, each of these hypotheses were based upon predicted EE derived from activity monitors worn at four locations corresponding to the left and right wrists, as well as left and right anterior hip along the beltline.

Primary Hypothesis

The null hypothesis was that predicted energy expenditure will equal actual energy expenditure for light, moderate, and vigorous intensity activities for any of the four activity monitor locations.

$$\mathbf{H_{\emptyset}: \mu_{A0} = \mu_{P0}, \mu_{A1} = \mu_{P1}, \mu_{A2} = \mu_{P2}}$$

$$\mathbf{H_{A}: \mu_{A0} \neq \mu_{P0}, \mu_{A1} \neq \mu_{P1}, \mu_{A2} \neq \mu_{P2}}$$

Where μ_{A0} = actual EE determined without allowance for a bout interruption (BI0), μ_{P0} = predicted EE determined with BI0, μ_{A1}= actual EE determined by allowing for a 1-minute bout interruption (BI1), μ_{P1} = predicted EE with BI1, μ_{A2} = actual EE determined by allowing for a 2-minute bout interruption (BI2), and μ_{p2} = predicted EE with BI2.

Secondary Hypothesis

The null hypothesis was that predicted physical activity time will equal actual physical activity time for light, moderate, and vigorous intensities activities for any of the four activity monitor locations.

$$\mathbf{H_{Ø}: \mu_{A0} = \mu_{P0}, \mu_{A1} = \mu_{P1}, \mu_{A2} = \mu_{P2}}$$

$$\mathbf{H_{A}: \mu_{A0} \neq \mu_{P0}, \mu_{A1} \neq \mu_{P1}, \mu_{A2} \neq \mu_{P2}}$$

Where μ_{A0} = actual T determined without allowance for a bout interruption (BI0), μ_{P0} = predicted T determined with BI0, μ_{A1}= actual T determined by allowing for a 1-minute bout interruption (BI1), μ_{P1} = predicted T with BI1, μ_{A2} = actual T determined by allowing for a 2-minute bout interruption (BI2), and μ_{p2} = predicted T with BI2.

Delimitations

1. The scope of this study was limited to a lab controlled setting in the Movement Science Lab of Montana State University in Bozeman, Montana.
2. The study population was delimited to habitual runners in Bozeman, Montana.

Operational Definitions

Kilocalorie (Kcal):	The amount of heat required to raise the temperature of 1 kg of water 1° C.
Energy Expenditure (EE):	Total kilocalories expended to complete a task (kcal).
Activity Energy Expenditure (AEE):	Relative energy expenditure to perform a task above resting (kcals/kg/min or kcals/day).
Physical Activity:	Any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level.
Metabolic Equivalent (MET):	A unit used to estimate the amount of oxygen used by the body during physical activity. 1 MET = the amount of energy expended during 1 minute at rest, which is approximately 3.5 ml/kg/min.
Bout	A period of time when an individual is engaged in a particular activity.
Bout Interruption:	Cessation of activity for a period of time during a particular session of physical activity.
Activity Monitor:	A small device used to predict EE of physical activity through measurements of acceleration of the body.
Physical Activity Bout:	A continuous time period spent engaged in a particular physical activity.
Physical Activity Intensity:	The EE or MET level of a particular activity.
Physical Activity Duration:	The time spent engaged in an activity.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Obesity, diabetes, and cardiovascular disease are leading causes of mortality in the United States (Warburton et al., 2006). Currently, cardiovascular disease is the number one killer, resulting in the deaths of twenty-six thousand people each day (National Center for Chronic Disease Prevention and Health Promotion, 2003). Further, since incidence rates of obesity and diabetes are related to cardiovascular disease they also parallel incidence rates. While benefits of physical activity have been well known in the past, recent studies have revealed the ability of physical activity to reduce the likelihood of developing chronic diseases and decrease relative risk of death (Warburton et al., 2006; Ryan et al., 2006; Leonard, 2001). In a review of literature by Warburton et al. (2006), the authors reported a positive linear relationship between physical activity and health status. According to the research, even a moderate increase in physical activity has a positive impact on health status (Warburton et al., 2006; Ryan et al., 2006).

Due to the high prevalence rate of cardiovascular disease, obesity, and diabetes, current research is concerned with the ability to accurately measure free-living physical activity. Physical activity is made up of four domains that include frequency, intensity, duration, and the mode of activity. Whereas frequency, duration, and mode of physical activity are easy to measure, physical activity intensity is more problematic. Furthermore, energy expenditure (EE), a common marker of physical activity intensity, is especially difficult to measure in activities of daily living, such as gardening or housework. According to Haggarty and McGaw (1988), knowledge of whole-body EE is important to accurately estimate the energy requirements for optimum health and performance.

An important consideration when measuring EE is that steady-state oxygen consumption (VO_2) is not achieved until 3-5 minutes at a given exercise intensity. This is because the onset of physical activity presents an energetic challenge to the body to provide enough adenosine triphosphate (ATP) to complete the task as efficiently as possible. Steady-state is the plateau in oxygen consumption during an aerobic task where the ATP demands of the skeletal muscle are met by aerobic metabolism. At the beginning of physical activity an individual will experience O_2 deficit, which is the difference between O_2 required for a given activity and actual O_2 consumption. Thus, when measuring VO_2 it is important to recognize that actual O_2 consumption, and therefore EE, gradually increases to a steady state level at the onset of physical activity and gradually decreases when activity ceases.

Methods for Measurement of Energy Expenditure

Many researchers have conducted studies to determine appropriate measures of EE (Haggarty & McGaw, 1988; Heil, 2002; Meijer, Westerterp, Koper, & Ten Hoor, 1989; Schmitz et al., 2005; Wolf, 1956). There are several techniques to estimate EE, including direct and indirect calorimetry, and doubly-labeled water, as well as several types of portable electronic devices, including heart rate monitors, pedometers, and accelerometry-based physical activity monitors. The difference between these methods is in how they purport to estimate EE. Depending on the situation, population, time and cost restraints, one method may be more appropriate than another. Each method has benefits and limitations to its use, thus it is up to the researcher or clinician to decide which method will be the most effective and efficient measure to estimate EE.

The most accurate measure of EE is direct calorimetry, which measures the production of heat. Direct calorimetry has been used for many years and is highly accurate with less than ±1% error (Laporte, Motoye, & Caspersen, 1985). However, direct calorimetry is conducted in special chambers, which makes it expensive and impractical for use in large populations. Limitations of direct calorimtery include the absence of true free-living conditions as well as restrictions on the habitual circumstances of daily activities.

Indirect calorimetry measures oxygen consumption (VO_2) and correlates highly with heat production. Expired air is collected through a mouthpiece, resulting in approximately ±2-3% error (Laporte et al., 1985). Indirect calorimetry is not as limiting as direct calorimetry because measurements are not confined to a chamber and can be conducted in lab or field settings with use of a portable metabolic system. Indirect calorimetry still has notable limitations which include the need to wear a metabolic system for collecting expired air. Furthermore, due to cost and invasiveness, indirect calorimtery is impractical for long-term measurement of EE. As a result, the use of indirect calorimetry is confined to lab or controlled field tests. Both direct and indirect calorimetry, though accurate, are not practical for measuring free-living EE. However, direct and indirect calorimetry can be used to validate other measures of physical activity because of their known accuracy (Laporte et al., 1985).

An alternative method that provides a measure of EE over time is the doubly-labeled water technique. First, subjects ingest water that contains isotopically labeled hydrogen and oxygen atoms. Next, urine samples are collected and examined for the proportion of unmetabolized water and water that has gone into the metabolism cycle. The doubly-labeled water technique, which takes anywhere from two days to several weeks, yields an overall estimate of EE. Although less invasive, it is still somewhat time consuming and expensive. Conversely, the doubly-labeled technique may be desired when measuring EE over long periods of time when compared to other methods such as direct or indirect calorimetry. An advantage of the doubly-labeled water technique is that it does not disrupt normal activities of the subject, which is important for an accurate estimate of EE over time (Haggerty & McGaw, 1988). Still, the doubly-labeled technique is limited to measures of overall caloric expenditure and not patterns of physical activity participation within the measurement period (Laporte et al., 1985).

Another technique for measuring EE is heart rate monitoring, which can be used over an extended period of time to assess physical activity. A heart rate monitor is a device that is worn around the chest at the level of the heart. Monitors typically consist of an adjustable one-inch thick band that transmit heart rate to a watch either worn by the subject or mounted in close proximity. Advantageously, heart rate is a direct measure of physical activity because it reflects intensity and duration. For example, as intensity and duration of physical activity increase, heart rate will also increase. In addition, there is a linear relationship between heart rate and oxygen consumption: as VO_2 increases heart rate proportionally increases (Laporte et al., 1985). However, reports that have assessed daily EE using heart rate monitors have been poor because the relationship between heart rate and VO_2 is not linear at a resting heart rate. Therefore, the use of a heart rate monitor to predict EE is more accurate when used at a higher intensity than resting state (Laporte et al., 1985).

Pedometers have also been used for measuring physical activity related to walking. Pedometers are small waist-worn devices that count steps during locomotion-based activities. Regular wearing of a pedometer allows individuals to track daily steps and monitor changes in walking habits over time. One disadvantage is that pedometers cannot determine the intensity of walking (Leenders et al., 2000). Despite this limitation, pedometers are popular because they are small, non-invasive, inexpensive, and have been shown to be reliable (Gretebeck & Montoye, 1992).

Though reliability of pedometers has been established, there is not much evidence that validate the use of pedometers in diverse populations. Additionally, there are many limitations to the use of pedometers, such as individual gait or walking patterns, wearing location and ground reaction force, different terrain, and body size. Due to the variability in pedometer output data accurate measures of EE is difficult. Despite problems with pedometer use, there are instances (such as locomotion activities in healthy individuals) where the use of pedometers is appropriate.

Self-reporting, which consists of recording physical activity sessions by an individual, is another technique that has been used to assess physical activity. Physical activity diaries, a form of self-reporting, are frequently used to keep track of daily physical activity. The advantages include ease of use in large-scale studies and the relative low cost to implement. To elicit a more accurate recall, researchers have made efforts to standardize interview techniques so that physical activity outcome variables can be compared. Nonetheless, self-reporting still depends on the following: accurate recall of physical activity by the subject, accurate interpretation of the recorded information, and valid formulae for converting data into EE (Leenders et al., 2000). Thus, self-reporting is not always an accurate way to monitor physical activity because individuals tend to overestimate EE and forget to record all activities. Also, the interpretation of an individual's physical activity by the researcher can affect the accuracy of the report. For instance, if the report is not very detailed, the researcher may falsely interpret some of the data. Moreover, the formulae used to convert physical activity to EE is an important consideration because some formulae give a more generalized output while others are more specific to the individual and activity.

A more recent method that has recently become popular for measuring EE is through the use accelerometry-based activity monitors. An accelerometry-based activity monitor measures accelerations, which are changes in velocity with respect to time. The accelerometer within the activity monitor is composed of a piezoelectric element that houses a seismic sensor. When the seismic sensor undergoes acceleration, it causes changes in the form of bending in the piezoeletric element. This causes a displaced charge to build up on one side of the sensor, which is recorded as a count. Therefore, the degree of "bending" determines how high of a count is recorded by the seismic sensor.

Furthermore, the counts are recorded in specified time epochs, which are the duration wherein the accelerations are recorded and summed. The summed counts over the specified time epoch are then converted into the raw output in counts/min (Chen & Bassett, 2005).

Activity Monitor Considerations

Though activity monitor use is more widespread than other measures of EE, there are many research considerations regarding the use of activity monitors during physical activity. Some concerns that have been addressed are: time epoch, number of axis of the activity monitor, monitoring frequency, user knowledge, and value calibration.

Measuring physical activity by accelerometry-based activity monitors consists of rapid sampling of counts over a specified time period of epoch. The time epoch determines how frequently data will be collected and is an important consideration when measuring different physical activities. For instance, the time epoch in which the activity monitor counts are recorded will affect the accuracy of the data. Shorter epochs (15-30 seconds) are more appropriate in intermittent activities and frequent bursts of short duration while longer epochs (1-minute) are more appropriate for continuous, lower intensity activities. Thus, activities with highly consistent accelerations over time, such as walking and running, have less variability (i.e., more accuracy) than leisure time activities such as sweeping and raking. In early studies, a 1-minute epoch was typically used to optimize the recording and storage capacity of the monitors. As technology has improved and memory capacity of activity monitors has increased researchers have been able to use shorter epochs, such as 30- or 15-seconds. To determine the appropriate time epoch, different analytical techniques have been developed to account for different types of physical activity. For example, a two-regression model used with ten-second epochs was developed to try to accommodate a wide range of activities. The two-regression model was more accurate in prediction of EE because it was able to distinguish between walking, running, and other activities (Crouter, Clowers, & Bassett, 2006). One consideration when using the ten-second epoch is the storage capacity of the accelerometer: a larger epoch length will store a larger number of days worth of data than a smaller epoch length. This is a consideration for the future technology of activity monitors (Crouter et al., 2006).

Another consideration is the number of planes (one, two, or three) in which the activity monitor can measure movement. The beam sensor in the piezoelectric element is generally most sensitive to movements in one axis of movement (vertical to the ground) and is usually therefore referred to as uniaxial. The piezoelectric element in the Actical activity monitor can also sense movements in other planes (vertical and horizontal), and is sometimes referred to as omnidirectional. Therefore, the degree that an activity monitor can measure movements in other planes or directions depends on the geometry, stiffness, and positioning of the seismic mass on its beam. To measure accelerations in multiple directions, several uniaxial units must be mounted orthogonally to one another (Chen & Bassett, 2005). In walking trials, a uniaxial activity monitor was able to accurately display a linear relationship between acceleration and EE. However, a uniaxial activity monitor was found inaccurate in measuring sedentary and running activities. As a result, researchers have evaluated triaxial activity monitors, which combine three independent sensors. By detecting accelerations in three-dimensional space, triaxial activity monitors theoretically improve accuracy in detecting accelerations, especially for sedentary activities. Thus, triaxial activity monitors may be more appropriate for measuring physical activity in sedentary populations. Both types of activity monitors underestimate EE in free-living conditions because accelerometers only measure physical activity. Underestimation of EE was also found in lower-intensity activities, but was improved by the use of a triaxial activity monitor over a uniaxial activity monitor (Chen & Sun, 1997).

An additional issue concerning the use of activity monitors for measuring physical activity is how frequently subjects should be monitored. A study by Gretebeck and Montoye (1992) evaluated how many days in the week subjects should be monitored. The researchers included pedometers, accelerometers, heart rate monitors, and daily caloric intake to measure EE. Subjects were monitored for seven days to determine if there were any differences in the methods of EE and determine the day-to-day variation in activity. Based on the results, five or six days were needed to estimate habitual physical activity. Weekend days and weekdays should be sampled to estimate habitual physical activity because subjects tended to be more active on weekdays than on weekend days (Gretebeck & Montoye, 1992).

The intricate composition of activity monitors is another research consideration because an advanced level of understanding is needed for proper use. Due to their complex structure, understanding exactly how an activity monitor works is not common knowledge to most researchers. When it comes to knowledge of activity monitors there are still many gaps and therefore five specific areas related to activity monitor use were identified: 1) monitor selection, quality and dependability, 2) monitor use protocol, 3) monitor calibration, 4) analysis of accelerometer data, and 5) integration with other data sources. These gaps in knowledge led researchers to convene a conference designed to address these issues in December 2004 titled, "Objective Monitoring of Physical Activity: Closing the Gaps in the Science of Accelerometry". The conference highlighted nine papers and ten posters on specific issues associated with activity monitor use and the best practices and recommendations for future research (Ward et al., 2005).

As a result of the gaps in activity monitor research, several publications on calibration emerged. One of these publications, written by Welk (2005), outlined the key goal in calibration research: the relationship between raw activity monitor output and actual levels of physical activity. Welk (2005) delineated how activity monitor output varies across a wide range of intensities and activities. Value calibration, which accounts for differences in individual activities and intensities, allows raw activity monitor counts to be converted into more meaningful units. The difficulty in value calibration is that there are unique relationships between movement and EE for different activities. It is not probable that a single equation or algorithm will accurately measure EE for all activities that an individual can perform. The goal for future research is to perform specific calibration studies on sample populations of similar characteristics to control for as much error as possible. This can help determine the appropriateness of equations and improve the utilization of activity monitors in different populations (Welk, 2005).

Gaps in the Research

An area that still needs to be addressed for future research is the analysis of activity monitor data. This area can be broken down into five specific issues: 1) defining a day, 2) handling incomplete data, 3) creating reporting standards, 4) determining bouts, and 5) handling spurious data. Of these specific issues, one area that remains to be addressed is the determination of bouts of physical activity in activity monitor data. A bout is considered to be a continuous session of physical activity. The minimum length for an activity to be considered a bout of activity has not been settled. To examine this issue, total duration of physical activity as well as each bout length and interruption should be measured. Currently, no physical activity bouts shorter than ten minutes are counted towards the daily goal of 30 minutes of moderate intensity physical activity. Within these ten minute bouts, it has been recommended that researchers allow for one or two minute bout interruptions. The reason for this is because in real life situations, interruptions such as stopping for a drink of water or slowing at a stop sign occur. When no interruptions are allowed, the number and duration of physical activity bouts counted decrease (Ward et al., 2005).

Based on this discrepancy concerning bout interruptions, the next step is to develop an algorithm that allows bout interruptions. Furthermore, after allowing for bout interruptions, there is a need to smooth out the raw activity monitor data. Since an activity monitor measures changes in velocity with respect to time, when movement ceases the activity monitor stops recording data. This yields no measure of physical activity during that particular interruption, resulting in lower predicted EE. The misrepresentation of physical activity by the activity monitor results in an inaccurate representation of an individual's actual EE. Thus, there is a need to develop an algorithm to smooth out the bout interruptions in raw activity monitor data so accurate predictions of EE are possible.

CHAPTER THREE

METHODOLOGY

Introduction

The purpose of this study was to compare predicted physical activity energy expenditure and time from an activity monitor with measured energy expenditure and time before and after applying a set of bout interruption rules

Subjects

Fifteen habitual runners from Bozeman, Montana, who ran at least 3 times/week for a duration of 30, minutes or run 2 times/week for 30 minutes and participated in endurance activities (e.g., cross country skiing or cycling) at least once per week for a duration of 30 minutes (approximately 90 minutes/week) over the previous three months, volunteered to participate in this study. Subjects read and signed an informed consent document (Appendix A), approved by the Montana State University Human Review Committee, explaining the requirements and potential risks of the study. Subjects were given a questionnaire (Appendix B) to determine their past and current running history, as well as Physical Activity Readiness Questionnaire (PAR-Q) (Appendix C) to screen for contraindications to moderate intensity walking and running.

Procedures

Participation in the study required two visits to the Montana State University Movement Science Laboratory (MSL) in Bozeman, Montana. During the first visit, which lasted approximately 60 minutes, demographics (e.g., age, height, weight) were recorded, an informed consent was signed, and tests for sitting resting energy expenditure (SREE) and maximal oxygen uptake (VO_{2MAX}) were administered. During the second visit, subjects completed 60 minutes of walking and running trials on a treadmill, where the entire visit lasted approximately 90 minutes.

First Laboratory Visit.

Subject Demographics. Following the measurement of demographic information, a running history questionnaire (Appendix D) was administered detailing the number of months and/or years running, average weekly mileage, weekly running frequency, past or current injuries, as well as a self-assessed classification of running ability (elite, competitive, or recreational).

Measurement of Sitting Resting Metabolic Rate (RMR). For the purpose of this study, activity energy expenditure (AEE) was defined as the EE of an activity above sitting resting EE (e.g., SREE). Sitting resting EE for each subject was calculated as an average EE over the last two of 15 minutes of sitting in an upright position while wearing noise canceling headphones.

<u>VO_{2MAX} Test</u>. Following the RMR test, subjects completed an incremental test to volitional exhaustion on a motorized treadmill. After a 5-minute warm-up at a self-selected speed on the treadmill, subjects performed the VO_{2MAX} test while oxygen uptake (VO_2), heart rate (HR), respiratory exchange ratio (RER), and minute ventilation (V_E) were measured. Starting at 160.8 m/min and a 2% grade, work rate was increased by 1% grade every minute until exhaustion (Appendix E). Maximal oxygen uptake (VO_{2MAX}) was defined as the point at which at least two of three criteria were met: 1) An RER measure ≥ 1.1; 2) A plateau in VO_2, observed when the two highest measurements were within 2.5 ml/kg/min of each other; 3) A maximal HR within ±10 beats of age-predicted max heart rate (APMHR). The highest five-second averaged HR recorded during the test was considered the subject's maximal heart rate (HR_{MAX}). This test was offered as an incentive for subject participation as well as a valuable demographic measure.

<u>Second Laboratory Visit</u>.

During the second laboratory visit subjects were fit with four activity monitors and a metabolic measurement system. Subjects wore two activity monitors secured with a Velcro strap on the dorsal side of each wrist with the arrow, indicating the most sensitive axis, pointing toward the elbow. Subjects wore the remaining two activity monitors like pedometers on the left and right hip just anterior to the iliac crest and in line with the mid-axially line of the thigh with the arrow pointing up towards the trunk. The orientation of the activity monitors at the wrist and hip locations are consistent with the research upon which the AEE prediction algorithms are based (Heil 2006). Based on results from pilot testing, activity monitor data was collected in 15-second epoch lengths to ensure timing and resulting data were consistent with recording by the metabolic system.

Subjects performed a series of one running (160.8 m/min or 6 MPH and 0% grade) and two walking trials (53.6 and 107.2 m/min, or 2 and 4 MPH, and 0% grade) on a treadmill. During each trial, subjects completed three five-minute walking/running bouts separated by successive one- and two-minute bout interruptions (i.e., quiet standing). The trial was then followed by a 3-minute slow walking break (26.8 m/min, or 1 MPH, and 0% grade) before beginning the next trial. The subjects were given direction to step on and off the treadmill with whatever technique felt comfortable, while keeping wrist and hip movement to a minimum during the one- and two- minute bout interruptions. While the order of testing within trials was the same for all subjects, the order of speeds tested across subjects was counterbalanced. Using walking and running VO_2 prediction equations (American College of Sports Medicine, 2006), the three treadmill speeds would require 2.5, 4.0 and 10.2 metabolic equivalents (METs) which classifies the intensities as light (< 3 METs), moderate (> 3 and ≤ 6 METs), and vigorous (> 6 METs), respectively. Bout interruptions of one and two minutes were suggested as "Best Practice Recommendations" by Ward et al. (2005) for evaluating free-living activity monitor data.

Instrumentation

The Actical® activity monitors (Mini Mitter Co., Inc., Bend, OR, USA) used for this study are lightweight (17 g), small (2.8 x 2.7 x 1.0 cm^3), water resistant, accelerometers capable of measuring acceleration due to bodily movement in three planes. According to the manufacturer, the Actical® is an omnidirectional accelerometer more sensitive to acceleration along one axis indicated by a blue arrow on the face of each monitor. Prior to testing all ten activity monitors were calibrated by the manufacturer set to sample in 15-second epochs.

A TrueMax 2400 Metabolic Measurement System (Parvo Medics, Salt Lake City, UT, USA) was used to measure oxygen uptake during measures of SREE and VO_{2MAX}. Subjects breathed room air through a mouthpiece consisting of one-way valves, which guided expired air into the analyzer through plastic tubing. Certified gas mixtures were used to calibrate the oxygen and carbon dioxide analyzers. Ventilation measurements were checked using a calibrated 3-liter syringe (Hans Rudolph, Inc., Kansas City, MO, USA). Oxygen uptake was calculated every 20 seconds during the VO_{2MAX} test and every 60 seconds during submaximal testing. Heart rate was continuously monitored during VO_{2MAX} testing by a Polar Accurex Plus telemetry-based heart rate monitor (Polar Electro, Inc., Woodbury, NY, USA), with an average HR recorded every five seconds.

Data Processing

Actual Activity Energy Expenditure.

Actual AEE values were calculated through measures from the metabolic system, which included oxygen consumption (VO_2, L/min) and carbon dioxide production (VCO_2, L/min). To compare metabolic data and activity monitor data the values had to be presented in the same units. In order to achieve this, minute-by-minute EE values were calculated using Weir's equation:

$$EE = 3.941 \times VO_2 + 1.106 \times VCO_2$$

where EE was measured in kcals and both VO_2 and VCO_2, calculated as the average values over the last two minutes for each activity, were measured in L/min. Actual AEE (AEE_A) was defined as the EE above that for sitting RMR calculated from measures of VO_2:

$$AEE = (EE - RMR)/M$$

where EE was the subject's measured EE for a specific activity and M was the subject's mass in kg.

Predicted Activity Energy Expenditure.

Predicted AEE (AEE_P) was calculated from raw activity monitor data in counts/min using previously validated hip and wrist double regression modeling algorithms (Table 3.1). Activity monitor data was collected in 15-second epochs to ensure that the start and end of each physical activity bout as well as each bout interruption were temporally alligned with the data from the metabolic system. After verifying the actual start time of the trials, the data was summed into 1-min epochs by adding four successive 15-second epoch values (counts/min) beginning one minute before the start of the first physical activity bout. To compare these values with values from the metabolic system in units of kcals, raw activity monitor data were first converted into minute-by-minute predicted AEE values (AEE_P, kcals/kg/min) using previously validated hip and wrist double regression modeling algorithms (Heil, 2006). Each algorithm calculated AEE by a four-step process based upon predefined cut points of raw activity data. If raw activity output was below 50 counts/min, AEE was considered to be zero kcals/kg/min for both the hip and wrist monitors. If the raw activity output was between 50 and 350 counts/min for the hip monitor or between 50 and 600 counts/min for the wrist monitor, AEE was given a constant value of 0.007565 kcals/kg/min. If the raw activity output was between lower cut points (350 and 600 counts/min for the hip and wrist monitors, respectively) and upper cut points (1,200 and 2,000 counts/min for the hip and wrist monitors, respectively) a prediction equation was used to estimate AEE. For data above the upper cut point (1,200 and 2,000 counts/min for the hip and wrist, respectively) an additional prediction equation was used. Table 3.1 displays the summarized algorithms.

Table 3.1. Summary of 2R algorithms for converting raw activity monitor output to activity energy expenditure (AEE) in adults (Heil, 2006).

Location	CP1	CP2	Constant AEE: 50 < AC < CP1	Predicted AEE: CP1 < AC < CP2	Predicted AEE: AC > CP2
Hip	350	1200	0.007565	AEE = 0.01217 + (5.268E-5) x AC	AEE = 0.02663 + (1.107E-5) x AC
Wrist	600	2000	0.007565	AEE = 0.008006 + (2.355E-5) x AC	AEE = 0.04184 + (3.960E-6) x AC

Note: AC = activity monitor output (counts/min); CP1 = lower AC cut point; CP2 = upper AC cut point; AEE = activity energy expenditure (kcals/kg/min).

Computational Example: A value of 557 is recorded from a hip-worn activity monitor during physical activity. Since 557 is between cut point 1 (CP1) and cut point 2 (CP2) the resulting equation is used to calculate AEE_P (Table 3.1):

$$AEE = 0.01217 + (5.268E\text{-}5) \times AC$$

where the resulting AEE value is 0.0415 kcals/kg/min. The AEE_P value is then transformed from units of kcals/kg into units of kcals by multiplying each value by the respective subject's body weight in kg.

Calculating Actual and Predicted Time.

Actual time (T_A) was calculated as the actual elapsed time spent at or above a moderate physical activity intensity, derived from measures of AEE from the metabolic system. Predicted time (T_P) was also calculated from the time spent at or above a moderate physical activity intensity. Each minute that produced a value at or above the moderate intensity cut point was summed to yield T_A and T_P for each subject. Moderate intensity cut points for each subject were calculated using previously validated AEE (kcal/kg/min) cut points (Heil, 2006). Activity energy expenditure cut points were determined by creating a plot of mean METs and mean AEE values for a variety of activities and then using linear regression to determine AEE. Table 3.2 displays the resulting AEE cut points.

Table 3.2. Summary of Heil's (2006) predicted AEE cut points for physical activity at light, moderate, & vigorous intensities.

	METs (metabolic equivalents)	AEE Cut Points (kcals/kg/min)
Light	< 3.0	< 0.0310
Moderate	≥ 3.0 – 5.9	≥ 0.0310 - 0.0831
Vigorous	≥ 6.0	≥ 0.0832

Note: AEE = activity energy expenditure (kcals/kg/min); 1 MET = 3.5 ml/kg/min

A constant value of 0.0310 kcal/kg/min was multiplied with each subject's body mass (kg) to yield an AEE moderate cut point value in kcals/min. Each minute that resulted in an AEE value above the subject's calculated moderate intensity cut point was summed to yield the number of minutes spent at or above a moderate intensity. The summed minutes were used to predict time for BI0, BI1, and BI2 conditions. For BI1 conditions, any single minute between successive activity bouts that was not above the moderate intensity cut point was counted and summed, while any single or two successive minutes between successive activity bouts that were not above the moderate intensity cut point were counted and summed for the BI2 condition.

Computing the Dependent Variables.

Following the data transformations described above, the actual and predicted AEE data were transformed into a collection of EE- and time-based variables for statistical analysis. Values for AEE_{A0}, AEE_{A1}, and AEE_{A2} were defined as the sum of AEE values both within and between defined bouts without an allowance for a bout interruption (BI0), with a 1-min BI allowance (BI1), and a 2-min BI allowance (BI2), respectively.

Values for AEE_{P0}, AEE_{P1}, and AEE_{P2} were defined as the sum of predicted AEE values for the three bout interruption conditions (BI0, BI1, BI2), respectively. These variables were created for each of the three treadmill conditions (i.e., light, moderate, and vigorous).

Actual physical activity time (T_A) was defined as the actual elapsed time AEE_A was at or above a moderate intensity cut point. Values for T_{A0}, T_{A1}, and T_{A2} were defined as the actual physical activity time spent at or above a moderate PA intensity for BI0, BI1, and BI2 conditions, respectively. Predicted physical activity time (T_P) for each monitor location was calculated as the elapsed time AEE_P was at or above a moderate intensity cut point. Values for T_{P0}, T_{P1}, and T_{P2} were defined as the sum of predicted T_P values for the three bout interruption conditions (BI0, BI1, BI2), respectively. These variables were created for each of the three physical activities intensities.

Statistical Analyses

Values of AEE_A for each BI definition (AEE_{A0}, AEE_{A1}, AEE_{A2}) and physical activity intensity (light, moderate, vigorous) were compared with the corresponding predicted values (AEE_{P0}, AEE_{P1}, AEE_{P2}) for each of the four activity monitor locations (left and right wrists and hips). Comparisons within intensities categories were made using a two-factor (5 AEE measures x 3 BI definitions) repeated measures analysis of variance (RMANOVA), while data for all three intensities were evaluated simultaneously using a multivariate RMANOVA. Similarly, values of T_A for each BI definition (T_{A0}, T_{A1}, T_{A2}) were compared with the corresponding predicted values (T_{P0}, T_{P1}, T_{P2}) for each of the four activity monitor locations (left and right wrists and hips) using the same multivariate RMANOVA model. All ANOVA's, as well as post-hoc analyses, were performed at the 0.05 alpha level.

Pilot Data Collection

Preliminary energy expenditure data was collected for three treadmill speeds (107.2, 160.8, and 214.6 m/min or 4, 6, 8 MPH) and two bout interruptions (1, 2 minutes) using a metabolic system and an activity monitor. At each speed the subject completed five minutes of walking, one minute of standing, five minutes of walking, two minutes of standing, and five minutes of walking with a one minute break between treadmill speeds.

Walking at 107.2 m/min (4 MPH), yielded MET values within the range of moderate physical activity (3- 6 METs) based on the ACSM's guidelines while MET values for both 160.8 and 214.6 m/min (6 and 8 MPH) were above the cut-off value. Data from the accelerometers were recorded in 15-second epochs and converted to minute-by-minute EE through double regression modeling algorithms. Data from the metabolic system was recorded in 20-seconds and also downloaded to minute-by-minute EE calculated using Weir's equation. The resulting EE from the accelerometer and the metabolic system were examined for differences in their purported measures of EE. Based on results of the preliminary trials, 15-second epochs were selected for the experimental trials to make certain that the bout interruptions could be clearly distinguished from the bouts of physical activity.

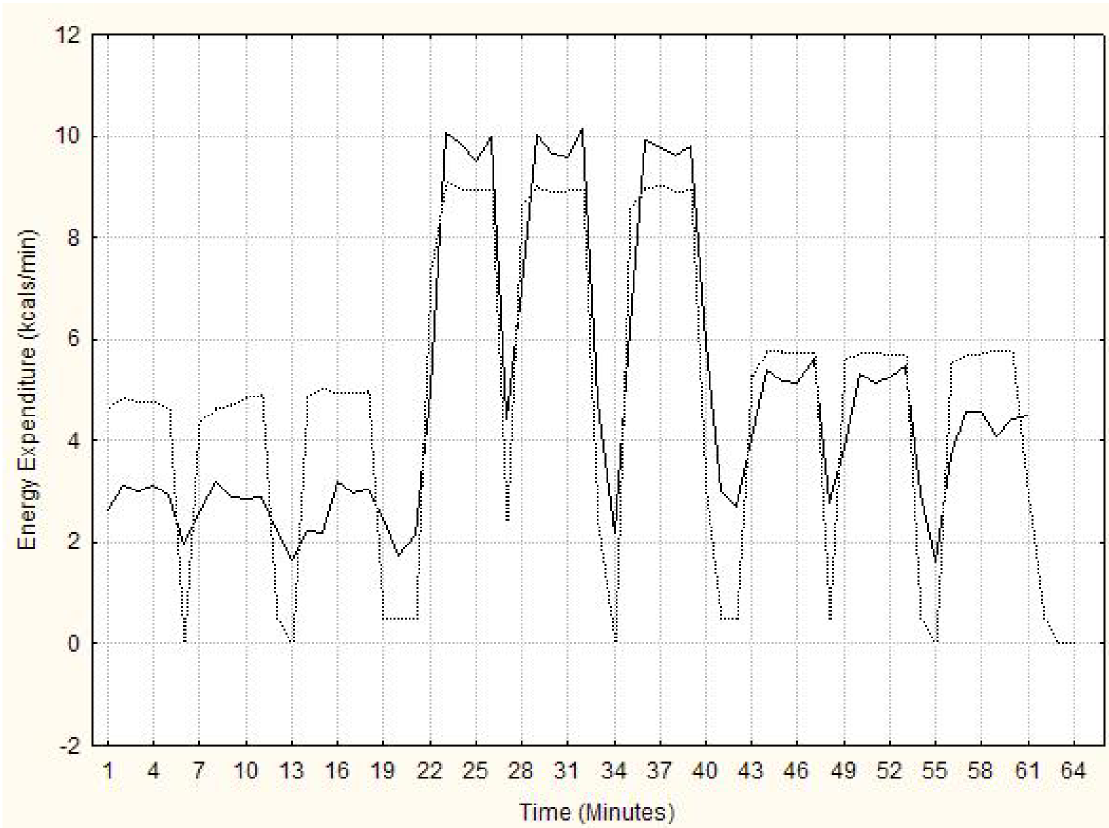

Figure 3.1. Actual data from a completed trial illustrating actual activity energy Expenditure (AEE_A) and predicted activity energy expenditure (AEE_P) for light, moderate, and vigorous physical activity (PA) intensities including 1- and 2-min bout interruptions within each PA intensity.

Note: The solid line represents AEE_A, while the dashed line represents AEE_P; AEE_P data is from a right hip-worn activity monitor; the order of intensity for this particular trial was: light, vigorous, moderate.

CHAPTER FOUR

RESULTS

The purpose of this study was to compare predicted physical activity energy expenditure and time from an activity monitor before and after applying a set of bout interruption rules with measured activity energy expenditure and time. Fifteen habitual runners (9 men, 6 women), between the ages of 19-26 years old volunteered to participate in this study. Age, height, and weight of the 15 subjects are summarized in Table 4.1. Maximal oxygen uptake was measured on 10 of the 15 subjects, with values ranging from 46.3 to 66.6 ml/kg/min, suggesting that the subjects were cardiovascularly fit (Table 4.2). The average resting metabolic rate (RMR) of the 15 subjects was (Mean±SD) 1.40 ± 0.34 metabolic equivalents (METs), with a range of 0.93 – 2.36 METs (Table 4.2). Body mass and RMR for the 15 subjects were linearly related, with the exception of one outlier (Figure 4.1).

Table 4.1. Summary statistics for subject demographics.

	n	Age (years)	Height (cm)	Weight (kg)
Men	9	23 ± 3	182.4 ± 3.6	74.7 ± 4.4
Women	6	22 ± 3	169.1 ± 6.9	60.4 ± 8.3

Note: n = 15; values are Mean ± SD

Table 4.2. Summary statistics for subject body mass, RMR, and VO_{2MAX}.

Subject #	Gender	Body Mass (kg)	RMR (ml/kg/min)	VO_{2MAX} (ml/kg/min)
S01	F	58	3.68	
S02	M	67.5	5.29	59.2
S03	M	75	5.11	
S04	M	73.1	6.23	
S05	F	66.1	4.03	46.3
S06	M	75.7	5.04	63.0
S07	F	71	4.59	50.5
S08	M	73.6	5.46	63.4
S09	M	74.8	4.62	
S10	F	58.5	4.41	55.8
S11	F	55	4.27	60.7
S12	F	46.9	3.26	
S13	M	83.6	6.34	64.1
S14	M	74.5	8.26	66.6
S15	F	67	5.25	52.3
Mean		68.02	5.06	
SD		9.69	1.23	
Range		46.9 – 83.6	3.26 – 8.26	

Note: RMR = Resting Metabolic Rate; VO_{2MAX} = maximal oxygen uptake; n = 15

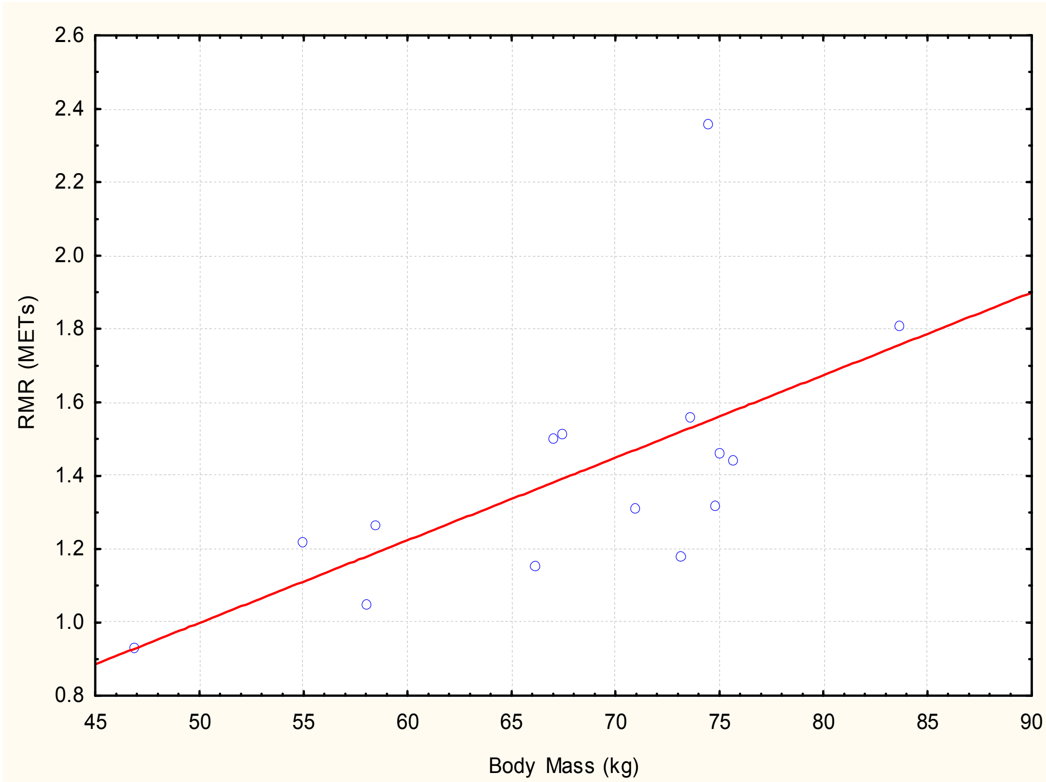

Figure 4.1. A comparison of body mass (kg) and RMR (METs) for 15 habitual runners. *Note:* RMR = resting metabolic rate; METs = metabolic equivalent; the line represents the linear trend of the data.

Metabolic data including average VO_2 (L/min and ml/kg/min), METs, and activity energy expenditure (AEE_A), were collected for each subject. Complete summaries of the data are presented for the three treadmill speeds (53.6, 107.2, and 160.8 m/min) in Tables 4.3-4.5, respectively.

Table 4.3. Summary of the metabolic data at the slowest walking speed (53.6 m/min) for each subject: Average VO_2 (L/min and ml/kg/min), METs, and AEE_A.

	VO_2 (L/min)	VO_2 (ml/kg/min)	METs	AEE_A (kcals/min)
S01	0.4	7.7	2.2	1.1
S02	0.5	8.1	2.3	1.2
S03	0.7	9.5	2.7	2.0
S04	0.6	8.8	2.5	1.9
S05	0.4	8.4	2.4	1.6
S06	0.6	8.4	2.4	1.7
S07	0.4	9.1	2.6	1.8
S08	0.4	9.1	2.6	1.9
S09	0.6	8.8	2.5	1.8
S10	0.6	9.8	2.8	1.6
S11	0.5	9.1	2.6	1.2
S12	0.5	9.5	2.7	1.3
S13	0.8	9.5	2.7	2.0
S14	0.4	8.4	2.4	0.7
S15	0.5	8.1	2.3	1.2

Note: VO_2 = oxygen uptake; METs = metabolic equivalent; AEE_A = actual activity energy expenditure.

Table 4.4. Summary of the metabolic data at a moderate walking speed (107.2 m/min) for each subject: Average VO_2 (L/min and ml/kg/min), METs, and AEE_A.

	VO_2 (L/min)	VO_2 (ml/kg/min)	METs	AEE_A (kcals/min)
S01	0.8	13.3	3.8	2.9
S02	0.9	13.3	3.8	2.9
S03	1.1	15.1	4.3	4.1
S04	1.0	14.0	4.0	3.8
S05	0.8	11.9	3.4	2.7
S06	1.1	15.1	4.3	4.1
S07	1.2	16.5	4.7	4.5
S08	1.1	14	4.0	3.8
S09	0.4	15.1	4.3	4.2
S10	1.0	16.8	4.8	3.6
S11	0.8	15.1	4.3	2.9
S12	0.5	15.8	4.5	2.6
S13	0.5	17.9	5.1	5.5
S14	1.0	13.7	3.9	2.7
S15	0.9	13.0	3.7	2.8

Note: VO_2 = oxygen uptake; METs = metabolic equivalent; AEE_A = actual activity energy expenditure.

Table 4.5. Summary of the metabolic data at the fastest speed (160.8 m/min) for each subject: Average VO_2 (L/min and ml/kg/min), METs, and AEE_A.

	VO_2 (L/min)	VO_2 (ml/kg/min)	METs	AEE_A (kcals/min)
S01	1.3	22.4	6.4	5.4
S02	1.7	24.5	7.0	6.7
S03	1.8	24.5	7.0	7.5
S04	1.7	23.1	6.6	7.1
S05	1.6	24.5	7.0	6.9
S06	0.5	23.1	6.6	7.1
S07	1.8	24.9	7.1	7.6
S08	1.8	23.1	6.6	7.2
S09	1.8	24.5	7.0	7.7
S10	0.4	28.4	8.1	6.9
S11	0.4	24.2	6.9	5.3
S12	1.2	25.2	7.2	4.8
S13	2.3	27.0	7.7	9.3
S14	1.8	24.5	7.0	6.7
S15	0.5	20.0	5.7	5.1

Note: VO_2 = oxygen uptake; METs = metabolic equivalent; AEE_A = actual activity energy expenditure.

Post hoc Data Processing

A Tukey's 1 degree of freedom test for nonadditivity was used to test for normality of the data at a 0.05 alpha level. The results revealed that the AEE data were non-normally distributed. Consequently, the AEE data were log-transformed, reanalyzed using a RMANOVA, and then were back transformed for all subsequent data presentations.

Comparison of Actual and Predicted Activity Energy Expenditure

Actual activity energy expenditure (AEE_A) values were compared after applying three bout interruption rules: without allowance for a bout interruption (BI0), allowance for a 1-minute bout interruption (BI1), and allowance for a 2-minute bout interruption (BI2). Predicted AEE (AEE_P) was measured from four activity monitor wearing locations: right hip (RH), left hip (LH), right wrist (RW), and left wrist (LW). These AEE_P values were also compared with each of the three BI rules. In general, allowing for a 1- or 2-minute BI significantly increased both actual and predicted AEE values at all PA intensities. Additional tables summarizing AEE_A and AEE_P values at light, moderate, and vigorous PA intensities for BI0, BI1, and BI2 conditions are in Appendix C.

At a light PA intensity mean AEE_A and AEE_P from all activity monitors (RH, LH, RW, LW) were significantly different across all BIs. The only exceptions were the increases from BI1 to BI2 for AEE_P from the RH, LH, and RW. Actual AEE, for example, increased on average by 1 kcal (25.5, 26.4, 27.4) when going from BI0 to BI1 and BI1 to BI2, respectively. Predicted AEE from all monitors increased on average by 0.5 kcals when going from BI0 to BI1. Left wrist monitors, which were significantly different across all BIs, increased on average by 0.5 kcals (37.5, 38.0) when going from BI0 to BI1 and by 0.7 kcals (38.0, 38.7) when going from BI1 to BI2, respectively (Table 4.6). Mean AEE_A values were statistically similar to AEE_P values from the RW monitors at each BI condition. Right-hip and left-hip AEE_P were statistically similar to each other at each BI condition but statistically different from all other variables. Additionally, right and left-wrist AEE_P were also statistically similar to each other (Table 4.6).

At a moderate PA intensity mean AEE_A and AEE_P from all activity monitors (RH, LH, RW, LW) were significantly different across all BIs. For example mean AEE_A increased on average by 2 kcals (59.6, 61.6, 64.0), while AEE_P increased on average by 1 kcal for RH and LH monitors and by 0.5 kcals for RW and LW monitors when going from BI0 to BI1 and BI1 to BI2 (Table 4.7). Mean AEE_A values were statistically similar to AEE_P values from the LH monitors at each BI condition. Additionally, at the BI2 condition AEE_A values were statistically similar to AEE_P from the RH. Mean AEE_P values from the RH and LH were similar to each other at each BI condition, while mean AEE_P values from the RW and LW were also statistically similar to each other at each BI condition (Table 4.7).

At a vigorous PA intensity mean AEE_A and AEE_P from all activity monitors (RH, LH, RW, LW) were significantly different across all BIs. For example, mean AEE_A increased on average by 4 kcals (113.6, 117.2, 121.9) while mean AEE_P increased on average by 3 kcals, (LW monitors: 469.4, 472.1, 475.2) when going from BI0 to BI1 and BI1 to BI2, respectively (Table 4.8). Mean AEE_A values were statistically similar to AEE_P values from RH and LH monitors at all BIs and significantly different from AEE_P values from RW and LW monitors (Table 4.8).

Table 4.6. Actual and predicted activity energy expenditure (AEE) from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist) for light intensity treadmill walking.

Bout Interruption Rules	Actual AEE	Predicted AEE			
		Right Hip	Left Hip	Right Wrist	Left Wrist
No BI	^{A}25.5±1.6	^{B}53.6±2.9	^{B}59.2±3.7	^{AC}33.6±2.9	^{C}37.5±2.8
1-min BI	^{A}26.4±1.7	^{B}54.1±2.9	^{B}59.8±3.7	^{AC}34.1±2.9	^{C}38.0±2.7
2-min BI	^{A}27.4±1.8	^{B}54.4±2.9	^{B}60.1±3.7	^{AC}34.4±2.9	^{C}38.7±2.8

Values are Mean±SE kcals; BI = bout interruption; ^{A,B,C} values with the same letter are statistically similar for the same BI rule.

Table 4.7. Actual and predicted activity energy expenditure (AEE) from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist) for moderate intensity treadmill walking.

Bout Interruption Rules	Actual AEE	Predicted AEE			
		Right Hip	Left Hip	Right Wrist	Left Wrist
No BI	^{A}59.6±3.7	^{B}79.4±3.5	^{AB}70.9±3.4	^{C}152.8±11.0	^{C}150.2±13.2
1-min BI	^{A}61.6±3.8	^{B}80.7±3.5	^{AB}72.1±3.6	^{C}153.4±11.0	^{C}150.9±13.2
2-min BI	^{A}64.0±4.0	^{A}81.9±3.5	^{A}73.1±3.7	^{B}153.9±11.0	^{B}151.5±13.2

Values are Mean±SE kcals; BI = bout interruption; ^{A,B,C} values with the same letter are statistically similar for the same BI rule.

Table 4.8. Actual and predicted activity energy expenditure (AEE) from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist) for vigorous intensity treadmill running.

Bout Interruption Rules	Actual AEE	Predicted AEE			
		Right Hip	Left Hip	Right Wrist	Left Wrist
No BI	[A]113.6±5.1	[A]132.1±6.0	[A]126.0±5.4	[B]472.7±19.5	[B]469.4±20.3
1-min BI	[A]117.2±5.3	[A]135.0±6.2	[A]128.5±5.5	[B]475.3±19.8	[B]472.1±20.5
2-min BI	[A]121.9±5.5	[A]138.1±6.3	[A]131.2±5.7	[B]478.1±19.9	[B]475.2±20.6

Values are Mean±SE kcals; BI = bout interruption; [A,B,C] values with the same letter are statistically similar for the same BI rule.

There were several apparent trends when comparing the actual and predicted AEE values. At a light PA intensity, AEE_A values were similar to AEE_P values from right and left wrist-worn activity monitors while right and left hip-worn activity monitors tended to over-predict AEE (Table 4.6). As intensity increased, wrist-worn activity monitors tended to over-predict AEE, while hip-worn activity monitors were more similar to AEE_A (Tables 4.7-4.8). In general, wrist-worn activity monitors tended to have higher AEE_P values than hip-worn activity monitors at moderate and vigorous PA intensities (Tables 4.7-4.8). In contrast, hip-worn monitors tended to have higher AEE_P values at a light PA intensity. All AEE_P values from each activity monitor wearing location (RH, LH, RW, LW) tended to have higher mean values than AEE_A values at all PA intensities and BIs. Data from a right hip-worn activity monitor graphically depicts the tendency for AEE_P values to be greater than AEE_A values (Figures 4.2-4.4).

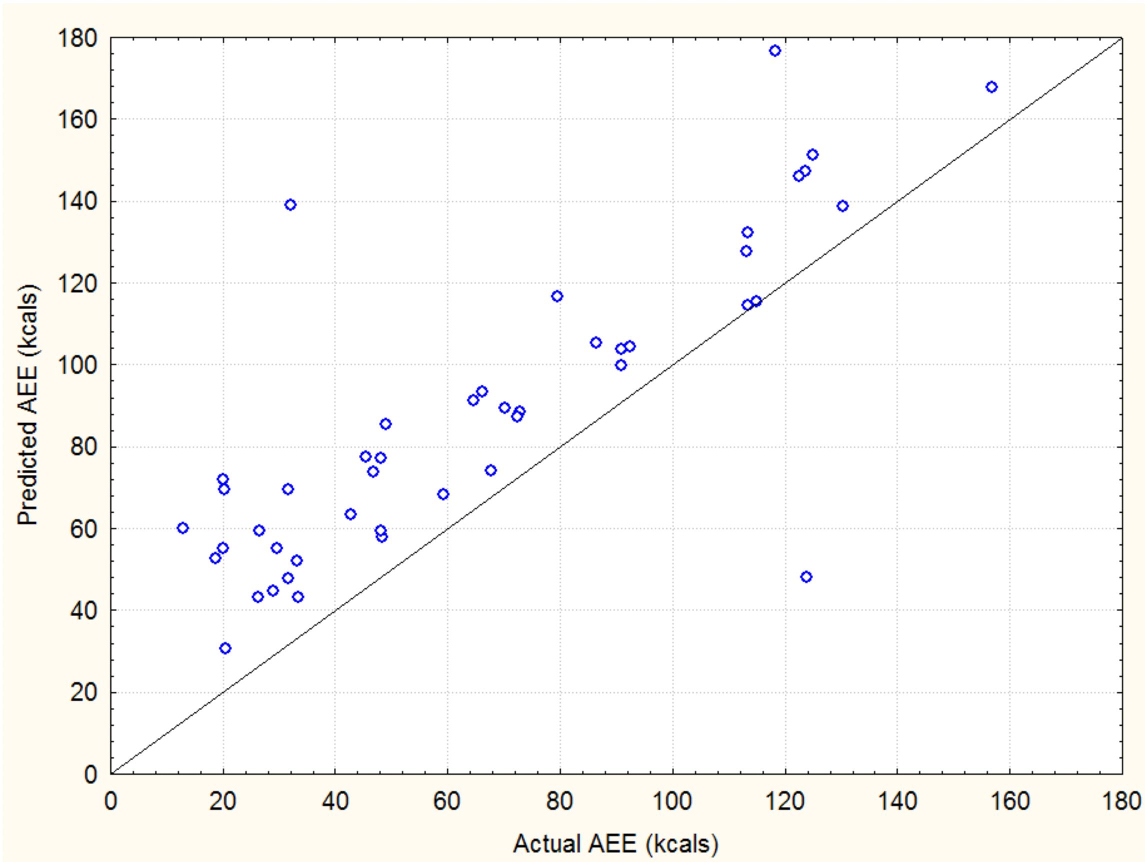

Figure 4.2. Comparison of actual activity energy expenditure (AEE_A) and predicted activity energy expenditure (AEE_P) without allowance for a bout interruption (BI0) at all three PA intensities (light, moderate, vigorous) from right hip-worn activity monitors. The black line represents the line of identity for the graph while the open circles represent each subjects' AEE values at all three PA intensities (light, moderate, vigorous).

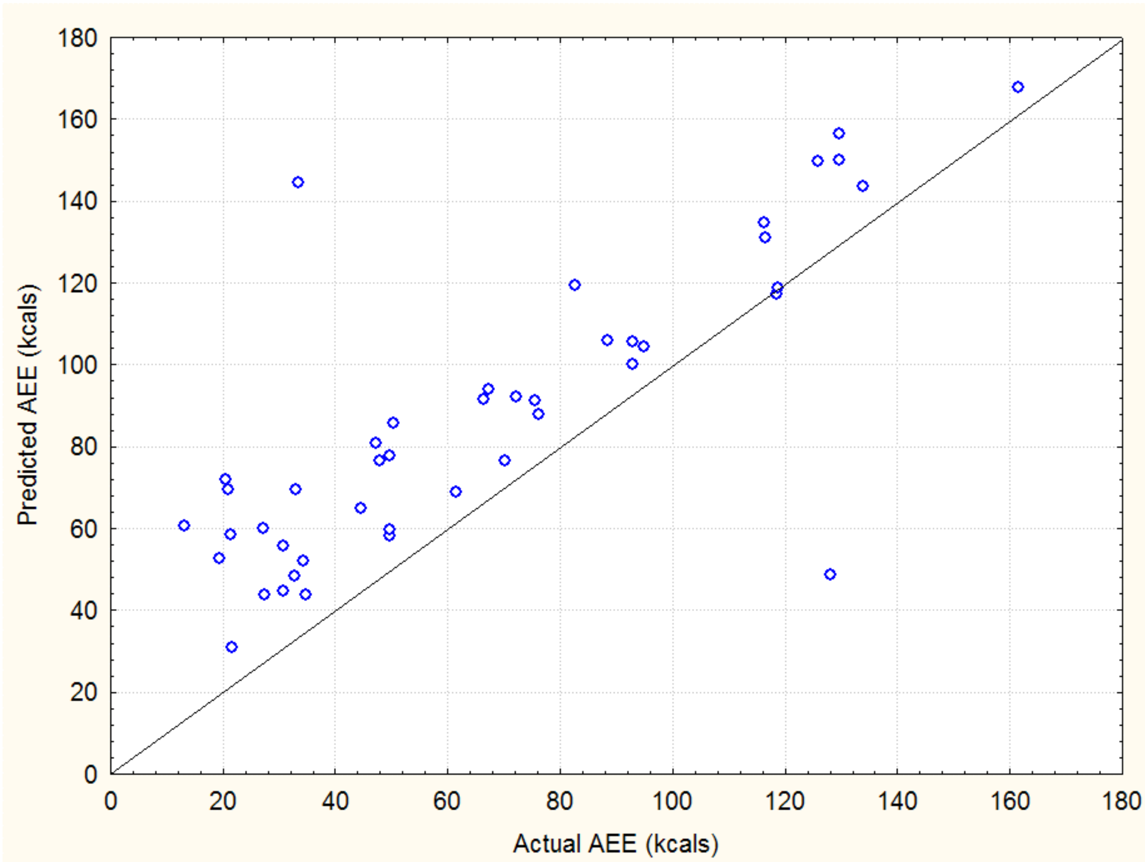

Figure 4.3. Comparison of actual activity energy expenditure (AEE_A) and predicted activity energy expenditure (AEE_P) with allowance for a 1-min bout interruption (BI1) at all three PA intensities (light, moderate, vigorous) from right hip-worn activity monitors. The black line represents the line of identity for the graph while the open circles represent each subjects' AEE values at all three PA intensities (light, moderate, vigorous).

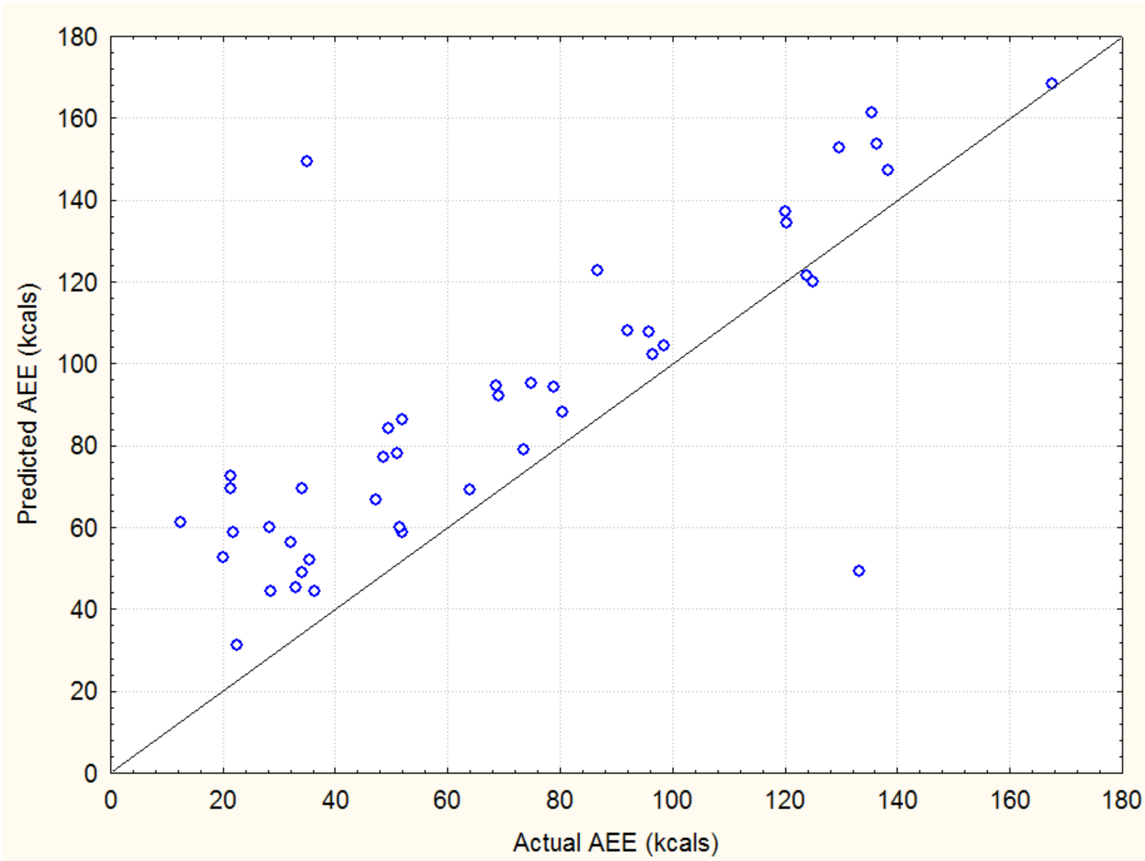

Figure 4.4. Comparison of actual activity energy expenditure (AEE_A) and predicted activity energy expenditure (AEE_P) with allowance for a 2-min bout interruption (BI2) at all three PA intensities (light, moderate, vigorous) from right hip-worn activity monitors. The black line represents the line of identity for the graph while the open circles represent each subjects' AEE values at all three PA intensities (light, moderate, vigorous).

Allowing for a BI within a bout of PA significantly influenced the AEE variables. Actual and predicted AEE values were significantly higher when going from BI0 to BI1 and BI1 to BI2 at light, moderate, and vigorous PA intensities. To further illustrate the effect of BIs on actual and predicted AEE a percentage increase between BI0 to BI1 and BI1 to BI2 were calculated (Table 4.9). When AEE_A values are expressed as a percentage, the increase between BI0 and BI1 or between BI1 and BI2 was 3-3.9% across all PA intensities. The percentage increase for AEE_P values was 0.3-2.7% across all PA intensities. The AEE percentage increases from hip-worn monitors tended to be greater at a vigorous PA intensity, while the increases from wrist-worn monitors tended to be greater at a light PA intensity. Actual AEE had the greatest percentage increases between BI0 to BI1 or between BI1 and BI2 at all PA intensities.

Table 4.9. Summary of actual and predicted activity energy expenditure from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist) expressed as a percent increase between bout interruption rules.

		Light	Moderate	Vigorous
Actual	BI0 to BI1	3.9%	3.3%	3.1%
	BI1 to BI2	3.0%	3.5%	3.8%
Right Hip AC	BI0 to BI1	1.0%	1.6%	2.0%
	BI1 to BI2	0.8%	1.5%	2.3%
Left Hip AC	BI0 to BI1	1.0%	1.6%	1.9%
	BI1 to BI2	0.5%	1.3%	2.1%
Right Wrist AC	BI0 to BI1	1.9%	0.4%	0.5%
	BI1 to BI2	1.2%	0.4%	0.6%
Left Wrist AC	BI0 to BI1	2.7%	0.5%	0.6%
	BI1 to BI2	0.3%	0.5%	0.7%

Note: BI0 = no bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; AC = activity monitor.

Comparison of Actual and Predicted Time

Similar to AEE, values of T_A for each BI (BI0, BI1, BI2) were compared with the corresponding predicted values (T_p) for each of the four activity monitor locations (left and right wrist and hip) (Table 4.10). Appendix C includes additional summary tables of T_A and T_P values for BI0, BI1, and BI2. Actual time spent at or above a moderate intensity was significantly different across the three BI rules. For example, T_A increased on average by 3 minutes (36.4, 39.0, 42.3) when going from BI0 to BI1 (36.4 to 39.0 mins) and BI1 to BI2 (39.0 to 42.3 mins). Predicted time for all monitors increased an average of 3 minutes when going from BI0 to BI1 and 5 minutes when going from BI1 to BI2 (Table 4.10). Mean T_A values were statistically similar to T_P from RW monitors at BI0 and BI1 conditions and statistically different from all other variables. Predicted time from RH and LH monitors were statistically similar to each other at all BIs, while T_P from LH monitors were also statistically similar to T_P from LW monitors at the BI2 condition. Likewise, T_P from RW and LW monitors were similar to each other at all BIs (Table 4.10).

Table 4.10. Actual and predicted time spent at or above a moderate intensity for BI0, BI1, and BI2 from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist).

Bout Interruption Rules	Actual Time	Predicted Time			
		Right Hip	Left Hip	Right Wrist	Left Wrist
No BI	[A]36.4±1.2	[B]49.5±0.7	[B]50.2±0.7	[AC]41.4±1.6	[C]43.1±1.4
1-min BI	[A]39.0±1.5	[B]52.4±0.7	[B]53.5±0.7	[AC]44.1±1.6	[C]45.9±1.5
2-min BI	[A]42.3±1.6	[B]58.4±0.4	[BC]57.9±0.6	[D]49.2±1.9	[CD]51.6±1.9

Values are Mean±SE minutes; BI = bout interruption; [A,B,C,D] values with the same letter are statistically similar for the same BI rule.

Similar to the trends observed for AEE, actual and predicted time values were significantly different for BI0, BI1, and BI2 conditions at all PA intensities. Allowing for a 1- or 2-minute BI significantly increased time spent at or above a moderate intensity at all PA intensities. When expressed as a percentage, the increase in average time between BI0 and BI1 and between BI1 and BI2 was 5.5-11.0% (Table 4.11). The increase tended to be larger going from BI1 to BI2 for all time variables. Also, the percent increases for time were larger than the percentage increase for AEE between BI0 and BI1 and between BI1 and BI2.

Table 4.11. Summary of actual and predicted time expressed as a percentage from four activity monitor wearing locations (right hip, left hip, right wrist, left wrist).

Bout Interruption Rules	Actual Time	Predicted Time			
		Right Hip	Left Hip	Right Wrist	Left Wrist
BI0-BI1	6.7%	5.5%	6.1%	6.1%	6.1%
BI1-BI2	7.8%	10.3%	7.6%	10.4%	11.0%

Note: BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption.

The results from the time variable revealed some similarities between T_A and T_P when allowing for a 1- or 2-minute BI. All time variables significantly increased between BI0 and BI1 and between BI1 and BI2 and all PA intensities. Predicted time tended to be higher than actual time at all BIs. Further, the hip worn-activity monitors tended to have higher predicted time values than the wrist-worn activity monitors.

CHAPTER FIVE

DISCUSSION

Previous studies have acknowledged that bout interruptions (BI) within a physical activity bout may affect physical activity outcome variables (Welk, 2005; Ward et al., 2005). Prior to this study, the affect of BI on activity energy expenditure (AEE) and time variables had not been systematically assessed. Accurate analysis of AEE and time is necessary because the Surgeon General's guidelines for daily physical activity include time and intensity: 30 minutes of moderate to vigorous physical activity consisting of 8-10 minute bouts. Since BI can affect both intensity and time, recognition of BI within a physical activity (PA) bout is imperative. This study was the first to compare the affect of different structured BIs (0, 1, and 2 minutes) utilizing a metabolic system and hip- and wrist-worn activity monitors across three different PA intensities (light, moderate, and vigorous) during walking and running trials on a treadmill. Actual values from the metabolic system for both AEE and time were used as a reference for comparison to predicted values from the activity monitors.

The Effect of Bout Interruptions

Comparisons of actual AEE (AEE_A) and predicted AEE (AEE_P) for each bout interruption rule (BI0, BI1, BI2) resulted in significant differences at light, moderate, and vigorous PA intensities. In general, allowing for a bout interruption during physical activity significantly increases AEE_A and AEE_P at all PA intensities. Likewise, comparisons of actual time (T_A) and predicted time (T_P) resulted in significant differences for each BI condition at all PA intensities. For both AEE and time variables, mean values increased when going from BI0 to BI1 and from BI1 to BI2. Thus, when the kcals and minutes that occurred during a BI were included in the analysis of PA bouts, total kcals and minutes spent at or above a moderate intensity increased.

Allowing for a BI is reasonable because a short break in PA (1 or 2 minutes) often occurs during exercise. When there is a pause in PA, an activity monitor will record 0 counts/min if no movement occurs, which is problematic when trying to accumulate bouts of 8-10 minutes. As a result, rules for BIs within a PA bout should be established since a BI significantly influences measures of PA-related AEE and time. If too few BIs are allowed, total AEE and time are decreased; if too many BIs are allowed, the PA bout starts to become more dependent on the BIs than the actual physical activity. It has been shown by Masse et al., (2005) that allowing for a 1- or 2-minute interruption anytime during a PA bout results in higher moderate-to-vigorous physical activity (MVPA) values than allowing for no interruption. Also, in a physically active population, allowing for an interruption may have a greater impact on the time spent at a MVPA intensity (Masse et al., 2005). Based upon the results of this study it seems reasonable to allow for one 1- or 2-minute BI per 10 minute PA bout. This would allow for a BI, while still relying more on the PA itself to influence measures of AEE and time.

Actual Versus Predicted AEE and Time

Actual AEE values were lower than AEE_P values from all activity monitor wearing locations (RH, LH, RW, LW) and all PA intensities. The tendency for activity monitors to over-predict activity energy expenditure during walking, especially at higher intensities, has been established in previous studies (Montoye et al., 1983; Ward et al., 2005; Welk, 2005). At faster walking speeds, such as 107.2 and 160.8 m/min (4 and 6 MPH), the predicted AEE values from the wrist-worn monitors are not a reflection of the actual energetic cost of walking. At faster walking speeds the arms are more likely to be swinging faster, thus resulting is higher values from the wrist-worn monitors. The higher predicted AEE values from the wrist-worn monitors suggest that the wrist is not the desirable location for monitoring locomotion with an activity monitor. The predicted AEE values from the hip-worn activity monitors were much closer to the actual AEE values, especially at 107.2 and 160.8 m/min. At 53.6 m/min (2 MPH), predicted AEE values from the hip-worn activity monitors were higher than the wrist-worn activity monitors, which could be an artifact of the slow walking speed. A speed of 53.6 m/min was a slow pace for most of the subjects in this study, who were healthy, fit, habitual runners. The slow walking speed may have altered the subjects' normal walking gait causing each step to be more accentuated and resulting higher predicted AEE values from the hip-worn monitors.

Actual time was also lower than predicted time for all activity monitor wearing locations (RH, LH, RW, LW). Since time was defined as the sum of minutes spent at or above a moderate intensity cut point, and predicted AEE values from the activity monitors were higher than actual AEE values, it was expected that predicted time would be higher than actual time. Another important note is that each subject actually spent 45 minutes walking on the treadmill during the trials. However, not all 45 minutes spent on the treadmill were at or above a moderate intensity. The time variable for this study was defined as the time spent at or above a moderate intensity. Since it takes 2-3 minutes to reach a steady-state in physical activity, not all 45 minutes of walking could be expected to be at or above a moderate intensity. Actual time for all BIs was lower (36.4, 39.0, 42.3 mins, respectively) than the time spent on the treadmill (45 minutes) because of the 2-3 minutes required to reach a steady-state in physical activity. In contrast, since activity monitors measure accelerations there is no time required to reach a steady-state during physical activity and thus predicted time tended to be higher than the time spent on the treadmill. Average T_P from hip-worn monitors tended to be higher for all BI definitions than the time spent walking on the treadmill, while average T_P from wrist-worn monitors was lower for BI0 and BI1 and higher for BI2 conditions (Table 4.9).

Activity Monitor Considerations

At moderate and vigorous physical activity intensities, AEE_P from wrist-worn activity monitors were significantly higher than AEE_P from hip-worn activity monitors. There is a tendency for wrist-worn activity monitors to overestimate AEE in locomotion activities. Most previous studies have validated activity monitor placement at the hip because it is closer to the body's center of mass and better at estimating EE (Hendelman et al., 2000; Ward et al., 2005; Welk, Schaben, & Morrow, 2004). During human locomotion, activity monitors are more accurate in predicting AEE when worn at the hip as opposed to the wrist. Also, gait patterns as well as walking speed can affect the accuracy of an activity monitor. Individual differences of subjects in this study along with the treadmill walking speeds (53.6, 107.2, 160.8 m/min) may have influenced the raw activity monitor data, resulting in different AEE_P values from hip- vs. wrist-worn activity monitors.

At moderate and vigorous physical activity intensities there was a tendency for the right hip- and wrist-worn activity monitors to be slightly higher than the left hip- and wrist-worn activity monitors. This could be a result of right side dominance. No guidelines were given to the method that subjects were to step on and off the treadmill, which could have resulted in stepping on and off with the dominant side first. This could cause greater movement from the right side of the body, resulting in differences from right and left sides of the body.

Throughout light physical activity conditions, wrist worn activity monitors tended to underestimate AEE. At a walking speed of 53.6 m/min, the light PA condition may have resulted in less movement of the arms and consequently lower predicted AEE values from wrist-worn activity monitors.

As walking speed increased, AEE_P from hip-worn activity monitors became closer to actual AEE than the AEE_P values from wrist-worn activity monitors. At 53.6 m/min, AEE_P from wrist-worn activity monitors was closer to actual AEE and lower than AEE_P from hip-worn activity monitors. However, at 107.2 and 160.8 m/min, AEE_P from hip-worn activity monitors was closer to actual AEE and lower than AEE_P from wrist-worn activity monitors (Tables 4.5-4.7). As walking speed increased, AEE_P from hip-worn activity monitors was more reflective of actual AEE of locomotion on account of more movement of the hips. At 53.6 m/min, the speed of the treadmill was not fast enough to cause much movement of the hips while walking. Consequently, as speed increased AEE_P values from the hip-worn activity monitors were more accurate in predicting AEE. In contrast, wrist-worn activity monitors over-predicted AEE at faster walking speeds. As speed increased, motion of the arms increased and resulted in AEE_P values that were not reflective of the actual AEE of locomotion. Although the wrist is often the desired location for activity monitor placement, the wrist tends to over-predict AEE in locomotion. Most previous studies have validated wrist-worn activity monitors in free-living PA studies, not during walking trials (Webster, 2007; Welk, 2005). Thus, the results of this study suggest that wrist-worn activity monitors may not be the most desirable site for monitoring AEE during locomotion.

Developing Algorithms

The standardization of activity monitor data reduction is an issue that needs clarification before recommendations for the development of algorithms can be suggested. An algorithm, in reference to activity monitor data processing, is a set of analytical steps that converts raw activity monitor data to practical units for measuring PA. For example, the double regression modeling algorithms developed by Heil (2006) converts raw activity monitor data to AEE in kcals/kg/min using a multistep decision tree approach. A study by Masse et al. (2005) sought to compare the impact of different combinations of decision rules on a common data set. Four algorithms were developed that took into account issues such as: number of continuous zeros used to identify the wearing period, minimal wear requirement for a valid day, spurious data, number of days needed to compute PA recommendation, and duration of interruptions when extracting bouts. The same data set was analyzed with four different algorithms to provide insight on the impact of the various issues. The results of the study indicated that using different decision rules on activity monitor data affected several important outcome variables of PA. Although Masse et al., (2005) considered different durations of BIs, each algorithm had several issues (stated previously) that were varied. Therefore, the influence of BIs on PA outcome variables could not be individually assessed. Currently, there are no published studies that solely address the affect of BIs on activity monitor data reduction. The present study was the first to systematically assess the affect of BIs on physical activity outcome variables in treadmill walking and running. The results of this study can be useful in future development of algorithms for more accurate analysis of free-living activity monitor data.

Daily Physical Activity Guidelines

The results of this study can be applied to the Surgeon General's guidelines for daily PA. Since the guidelines for daily physical activity are based on time and intensity, 30 minutes of moderate to vigorous intensity accumulated in 8-10 min bouts, accurate measurement of AEE and time are important. When allowing for a BI, as recommended by the results of this study, physical activity outcome variables from an activity monitor are more reflective of the actual values of the activity. The Surgeon General's guidelines for physical activity time start when movement begins and end with the cessation of movement. The guidelines do not take into account the time it takes to reach a physiological steady-state in physical activity. Consequently, not all movement time spent within a PA bout will be at or above a moderate intensity. In this study, T_A was derived from measures of AEE from a metabolic system and took into account the time required to reach a physiological steady-state. Predicted time values, in contrast, were measured by activity monitors and did not take into account time required to reach steady-state PA. As a result, T_P values are more consistent with the Surgeon General's guidelines since they do not take into account time required to reach a steady-state in PA.

Study Limitations

Resting metabolic rate (RMR) for each subject, which was estimated by averaging the last 2 of 15 minutes of sitting in a supine position, could have affected AEE and time variables since AEE was defined as the EE above that of resting. Although most subjects were relaxed after a few minutes, the estimated RMR values may not have been accurate. Subjects were not required to refrain from physical activity or consume caffeinated beverages before testing. Prior exercise and/or diet could cause RMR values to be falsely elevated and subsequently affect the analysis. However, these uncontrolled variables would only have a slight impact on RMR.

Another limitation of this study was the small homogeneous study population: all subjects were healthy and relatively fit, with ages ranging from 21-26 years. A requirement for participation in this study was to be a habitual runner. Consequently, volunteers for this study tended to be younger and more physically fit than the average population. Age, height, and weight of the subject can influence locomotion and may affect physiological variables, such as energy expenditure. Younger, healthy individuals will most likely have lower AEE values for activities such as walking and running compared to older and/or overweight individuals.

CHAPTER SIX

CONCLUSIONS

This study indicates that allowing for a bout interruption (BI) within a physical activity (PA) bout significantly increases measures of activity energy expenditure (AEE) and time during overground walking and running. Treadmill speeds of 53.6, 107.2 and 160.8 m/min were chosen to elicit MET values that corresponded to light, moderate, and vigorous PA intensities. Actual AEE was measured by a metabolic system, while actual time was derived from the evaluation of actual AEE. Predicted AEE and time were measured by four activity monitors worn on the left and right hip and wrist. Allowing for a 1- or 2-minute BI significantly increased mean AEE and time spent at or above a moderate intensity for both actual and predicted variables at light, moderate, and vigorous PA intensities. As a result, rules for BIs within a PA bout should be established since BIs significantly influence PA outcome variables. Allowing for BIs within a PA bout makes it easier to reach the daily goal of 30 minutes of moderate to vigorous PA accumulated in 8-10 minute bouts as determined by activity monitors.

The results of this study have practical applications for future research. This study was the first to systematically assess the affect of BIs on PA bouts. Since BIs significantly influence PA outcome variables, such as AEE and time, further investigation of BIs as well as other PA outcome variables is necessary. The results from this study are a starting point for future research regarding activity monitor data reduction and the development of algorithms. As delineated by Ward et al. (2005), there are many areas of activity monitors that have yet to be addressed, including analysis of activity monitor data. Since BIs complicate accurate measurement of energy expenditure within activity monitor data, rules for the allowance of 1- or 2-minute BIs should be established to allow for more accurate measurement of physical activity.

REFERENCES

Chen, K.Y., & Bassett Jr., D.R. (2005). The technology of accelerometry-based activity monitors: current and future. *Medicine and Science in Sports and Exercise, 37(11)*, S490-S499.

Chen, K.Y., & Sun, M. (1997). Improving energy expenditure estimation by using a triaxial accelerometer. *Journal of Applied Physiology*, *83*, 2112-2122.

Crouter, S.E., Clowers. K.G., & Bassett, Jr., D.R. (2006). A novel method using accelerometer data to predict energy expenditure. *Journal of Applied Physiology*, *100*, 1324-1331.

Gretebeck, R.J., & Montoye, H.J. (1992). Variability of some objective measures of physical activity. *Medicine and Science in Sports and Exercise, 24(10)*, 1167-1172.

Haggerty, P., & McGaw, B.A. (1988). Non-restrictive methods for measuring energy expenditure. *Proceedings of the Nutrition Society*, *47*, 365-374.

Heil, D.P. (2002). Estimating energy expenditure in wildland fire fighters using a physical activity monitor. *Applied Ergonomics*, *33*, 405-413.

Heil, D.P. (2006). Predicting activity energy expenditure using the actical activity monitor. *Research Quarterly for Exercise and Sport*, *77*, 64-80.

Hendelman, D., Miller, K., Baggett, C., Debold, E., Freedson, P. (2000). Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Medicine and Science in Sports and Exercise*, *32(9)*, S442-S449.

Laporte, R.E., Montoye, H.J., & Caspersen, C.J. (1985). Assessment of physical activity in epidemiologic research: problems and prospects. *Public Health Report*, *100*, 131-146.

Leenders, N.Y.J.M., Sherman, W.M., & Nagaraja, H.N. (2000). Comparison of four methods of estimating physical activity in adult women. *Medicine and Science in Sports and Exercise, 32*, 1320-1326.

Leonard, W.R. (2001). Assessing the influence of physical activity on health and fitness. *American Journal of Human Biology, 13*, 159-161.

Masse, L.C., Fuemmeler, B.F., Anderson, C.B., Matthews, C.E., Trost, S.G., Catellier, D.J., Trueth, M. (2005). Accelerometer data reduction: a comparison of four reduction algorithms on select outcome variables. *Medicine and Science in Sports and Exercise*, *37(11)*, S544-S554.

Meijer, G.A., Westerterp, K.R., Koper, H., & Ten Hoor, F. (1989). Assessment of energy expenditure by recording heart rate and body acceleration. *Medicine and Science in Sports and Exercise, 21*, 3.

Montoye, H.J., Washburn, R., Servais, S., Ertl, A., Webster, J.G., Nagle, F.J. (1983). Estimation of energy expenditure by a portable accelerometer. *Medicine and Science in Sports and Exercise*, *15(5)*, 403-407.

National Center for Chronic Disease Prevention and Health Promotion. (2003). Heart disease and stroke prevention: time for action. In *A Public Health Action Plan to Prevent Heart Disease and Stroke* (Section 1). Retrieved August 29, 2007, from http://www.cdc.gov/dhdsp/library/action_plan/pdfs/action_plan_3of7.pdf

Ryan, C.G., Grant, P.M., Tigbe W.W., Granat, M.H. (2006). The validity and reliability of a novel activity monitor as a measure of walking. *British Journal of Sport Medicine*, *40*, 779-783.

Schmitz, K.H., Treuth, M., Hannan, P., McMurray, R., Ring, K.B., Catellier, D., & Pate, R. (2005). Predicting energy expenditure from accelerometry counts in adolescent girls. *Medicine and Science in Sports and Exercise*, *37*, 155-161.

U.S. Department of Health and Human Services. (1996). *Physical activity and health: a report of the surgeon general executive summary*. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Promotion. Atlanta, GA.

Warburton, D.E.R., Nicol, C.W., & Bredin, S.S.D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, *174(6)*, 801-809.

Ward, D.S., Evenson, K.R., Vaughn, A., Rodgers, A.B., & Troiano, R.P. (2005). Accelerometer use in physical activity: best practices and research recommendations. *Medicine and Science in Sports and Exercise*, *37(11)*, S582-S588.

Webster, M.D. (2007). Reliably measuring habitual free-living physical activity with the actical® activity monitor. Unpublished master's thesis. Montana State University, Bozeman, Montana.

Weinstein, A.R., Sesso, H.D. (2006). Joint effects of physical activity and body weight on diabetes and cardiovascular disease. *Exercise and Sport Sciences Reviews*, *34(1)*, 10-15.

Welk, G.J. (2005). Principles of design and analyses for the calibration of accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise*, *37(11)*, S501-S511.

Welk, G.J., Schaben, J.A., & Morrow Jr., J.R. (2004). Reliability of accelerometry-based activity monitors: a generalizability study. *Medicine and Science in Sports and Exercise, 36*, 1637-1645.

Wolff, H.S. (1956). Modern techniques for measuring energy expenditure. *Proceedings of the Nutrition Society*, *15*, 77-80.

APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

PROJECT TITLE: *Influence of Bout Interruptions on Measured and Predicted Physical Activity During Treadmill Walking and Running*

PROJECT DIRECTOR: Stephanie M. Howe, Graduate Student
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Montana State University, Bozeman, MT 59717-3540
Phone: (406) 570-5197
E-mail: showe@montana.edu

FUNDING: This project is not funded

PURPOSE OF THE STUDY:

The purpose of this study is to compare the energy expenditure output from an activity monitor before and after applying a set of bout interruption rules with measured energy expenditure. A bout interruption is a 1-2 minute temporary stop of activity during a structured bout of activity. An example of a bout interruption would be a runner who stops for traffic at a stop light during a workout. Each subject will wear four activity monitors (two on each at left and right hip and wrist positions) while walking at two speeds (2 & 4 MPH) and running at one speed (6 MPH) on a treadmill. During the treadmill activity, each subject will wear a mask designed to collect expired air for metabolic analysis. The goal of this project is to gain a better understanding of how changes in treadmill speed and bout interruption length may alter the prediction of energy expenditure from an activity monitor.

Each participant is presented with this *Informed Consent Document* which explains the purpose of the testing, as well as expected risks and benefits associated with participation. It is the participant's responsibility to acquire medical clearance from his/her physician prior to lab testing. Each participant will also be screened by the project director using responses provided by participants in the **Physical Activity Readiness Questionnaire (PAR-Q)** (the PAR-Q is attached to the end of this document). This procedure is in compliance with policies formulated by the American College of Sports Medicine[1].

Please talk with the Project Director, Stephanie M. Howe, about any pre-existing health conditions that may limit your participation in this project *BEFORE* testing.

STUDY PROCEDURES:

You (the participant) will be required to make two visits to the Movement Science / Human Performance Lab (basement of Romney Building) within a one month period. The first visit will last approximately one hour and will be scheduled no sooner than 24 hrs after your last hard

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[1]American College of Sports Medicine (2006). *ACSM's Guidelines for Exercise Testing and Prescription* (7th edition). Lea & Fibiger; Philedelphia, PA.

workout. *If you use an inhaler to treat asthma, make certain to bring the inhaler with you to the lab.* You should arrive at the lab ready to engage in moderate to vigorous intensity walking and running. Therefore, you should dress in running shoes, running shorts and shirt. You should also eat, and drink fluids appropriately for the occasion. The second visit will last approximately two hours. You should be prepared to engage in moderate intensity walking and running and dress appropriately (same as above).

<u>First Laboratory Visit</u>

First, your body weight and height will be measured along with other pertinent information (e.g., age, gender). You will also be given a running history questionnaire detailing the number of months and/or years running, average weekly mileage, weekly running frequency, past or current injuries, as well as a self-assessed classification of running ability (elite, competitive, or recreational). Next, you will have your resting metabolic rate, or RMR, measured for later calculations of Activity Energy Expenditure (AEE), which is the energy expenditure of an activity above energy expenditure at rest. You will be fitted with a mask to collect expired air as well as noise canceling headphones and instructed to sit for fifteen minutes. Lastly, you will perform a test of maximal oxygen consumption (VO_{2MAX}) which will be used as a descriptive characteristic for this study's volunteers. Prior to the start of the VO_{2MAX} test, you will be familiarized with the testing protocol, fitted with a Polar heart rate monitor, and given a 5 minute warm-up on the treadmill at a self-selected speed and grade. The purpose of the warm-up is twofold: To warm up the body and to familiarize yourself with the treadmill. Once you are ready to begin the test, you will be fitted with a mask to collect expired air. The test will begin at 6 mph and 2% grade and will increase by 1% grade every minute until exhaustion. Testing will be terminated when you are not able to continue running at the current stage as indicated by grabbing onto the front bar of the treadmill.

<u>Second Laboratory Visit:</u>

The purpose of this visit is to collect energy expenditure and activity monitor data during treadmill walking and running with several planned bout interruptions. You will wear two activity monitors secured with a Velcro strap on the dorsal side of each wrist (like a wrist watch), as well as two activity monitors on the left and right hip (like a pedometer). To measure energy expenditure, you will also be fitted with a mask to collect expired air and a chest strap for measuring heart rate. You will perform a series of one running (6 MPH and 0% grade) and two walking trials (2 and 4 MPH, and 0% grade) on a treadmill. During each trial, you will complete three five-minute walking/running bouts separated by successive one- and two-minute bout interruptions. During each bout interruption, the treadmill will be stopped and you will stand quietly until the start of the next exercise bout.

<u>POTENTIAL RISKS</u>:

The submaximal treadmill testing carries no known risks. The exercise intensity is moderate to vigorous and you (the participant) are a habitual runner. VO_{2MAX} testing carries a risk of discomfort and also involves a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death. However, the possibility of such an occurrence is very slight (less than 1 in 10,000) since 1) you are in good physical condition with no known symptoms of heart disease, and 2) the test will be administered by trained personnel (American Red Cross CPR certified and aware of the lab's emergency action plan). *These risks should not exceed those experienced by trained athletes in actual race competition.* You control the amount of time spent on the treadmill and may terminate the test at any point. All possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place.

BENEFITS:
You will receive personalized feedback on your VO_{2MAX} test results. Additionally, study participants may request a summary of the study findings by contacting the Project Director, Stephanie M. Howe, by phone (406-570-5197) or by e-mail (showe@montana.edu).

CONFIDENTIALITY:
The data and personal information obtained from this study will be regarded as privileged and confidential. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data. The code list will be kept separate and secure from the actual data files.

FREEDOM OF CONSENT:
Participation in this project is completely voluntary. You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Stephanie M. Howe, by phone (406-570-5197) or by e-mail (showe@montana.edu) to discontinue participation.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in this project. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Stephanie M. Howe, at 406-570-5197.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721*.

PROJECT TITLE:	*The Influence of Bout Interruptions on Measured and Predicted Physical Activity During Treadmill Walking and Running*

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, ___________________________________ *(print your name)*, agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed:_____________________________ **Age** _______ **Date**__________

Subject's Signature

Witness: ______________________ ____________________ Date_____

Print Name *Sign Name*

APPENDIX B

PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise and completion of a PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the following questions carefully and check the ***YES*** or ***NO*** opposite the question if it applies to you.

YES	***NO***	
☐	☐	**1.** Has your doctor ever said you have heart trouble?
☐	☐	**2.** Do you ever have pains in your heart or chest?
☐	☐	**3.** Do you ever feel faint or have spells of severe dizziness?
☐	☐	**4.** Has a doctor ever said your blood pressure was too high?
☐	☐	**5.** Has a doctor ever said your blood cholesterol was too high?
☐	☐	**6.** Have you ever been diagnosed with diabetes mellitus?
☐	☐	**7.** Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
☐	☐	**8.** Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
☐	☐	**9.** Are you over the age of 65 or NOT accustomed to vigorous exercise?
☐	☐	**10.** Are you a habitual cigarette or cigar smoker?
		If *"Yes"*, how many years? __________
		If *"No"* AND you have recently quit smoking, how long ago did you quit? __________ (give answer in months or years)
☐	☐	**11.** Is there any other physical ailment not mentioned above that could be considered a health risk if you were to participate in the testing described by the Informed Consent Document? If "***Yes"***, please describe below...

*If you answered "**YES**" to one or more questions...*

If you have not recently done so, consult with your personal physician by telephone or in person before increasing your physical activity, taking a fitness test, or participating in the present research study. Tell the physician what questions you answered *"YES"* on PAR-Q or show a copy of this form. Be certain to talk with the principal investigator before preceding further with your involvement in this study.

*If you answered **"NO"** to <u>all</u> questions...*

You have reasonable assurance that your participation in the present study will not put you at higher risk for injury for illness.

NOTE: Postpone exercise testing if you suffer from minor illness such as a common cold or flu!

Your signature below indicates that you have filled out the preceding PAR-Q form to the best of your knowledge.

Signed:______________________________________Date____________
Subject's Signature

Signed:______________________________________Date____________
Project Technician

APPENDIX C

SUMMARY TABLES AND 95% CONFIDENCE INTERVALS FROM DEPENDENT VARIABLES

Table C1. Summary of actual activity energy expenditure (AEE_A) for BI0, BI1, and BI2 at light, moderate, and vigorous physical activity intensities.

LIGHT		BI0	BI1	BI2
	Mean	24.6	25.6	26.4
	SD	1.3	1.3	1.3
	SE	1.1	1.1	1.1
	L 95 CI	21.2	22.0	22.5
	H 95 CI	28.7	29.8	31.1
MODERATE		BI0	BI1	BI2
	Mean	58.1	60.1	62.3
	SD	1.2	1.3	1.3
	SE	1.1	1.1	1.1
	L 95 CI	51.2	52.9	54.9
	H 95 CI	66.0	68.2	70.9
VIGOROUS		BI0	BI1	BI2
	Mean	111.9	115.5	120.1
	SD	1.2	1.2	1.2
	SE	1.0	1.0	1.0
	L 95 CI	101.3	104.4	108.6
	H 95 CI	123.6	127.7	132.8

Note: values are in kcals; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; L 95 CI = lowest value of a 95% confidence interval; H 95 CI = highest value of a 95% confidence interval.

Table C2. Summary of predicted activity energy expenditure (AEE_P) for BI0, BI1, and BI2 from right hip-worn activity monitors at light, moderate, and vigorous physical activity intensities.

LIGHT		BI0	BI1	BI2
	Mean	52.4	52.3	53.2
	SD	1.3	1.2	1.2
	SE	1.1	1.1	1.1
	L 95 CI	46.3	46.8	47.2
	H 95 CI	59.3	59.9	60.2
MODERATE		BI0	BI1	BI2
	Mean	78.3	79.6	80.8
	SD	1.2	1.2	1.2
	SE	1.1	1.1	1.1
	L 95 CI	71.1	72.3	73.4
	H 95 CI	86.2	87.6	89.0
VIGOROUS		BI0	BI1	BI2
	Mean	130.3	133.0	136.1
	SD	1.2	1.2	1.2
	SE	1.0	1.0	1.0
	L 95 CI	118.2	120.6	123.4
	H 95 CI	143.5	146.8	150.1

Note: values are in kcals; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C3. Summary of predicted activity energy expenditure (AEE_P) for BI0, BI1, and BI2 from left hip-worn activity monitors at light, moderate, and vigorous physical activity intensities.

LIGHT		BI0	BI1	BI2
	Mean	57.6	58.1	58.5
	SD	1.2	1.3	1.3
	SE	1.1	1.1	1.1
	L 95 CI	50.2	50.8	51.2
	H 95 CI	66.1	66.5	66.9
MODERATE		BI0	BI1	BI2
	Mean	69.5	70.6	71.5
	SD	1.2	1.2	1.2
	SE	1.1	1.1	1.1
	L 95 CI	61.7	62.5	63.2
	H 95 CI	78.4	79.7	80.9
VIGOROUS		BI0	BI1	BI2
	Mean	124.3	126.7	129.4
	SD	1.2	1.2	1.2
	SE	1.0	1.0	1.0
	L 95 CI	113.1	115.3	117.7
	H 95 CI	136.6	139.3	142.3

Note: values are in kcals; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C4. Summary of predicted activity energy expenditure (AEE_P) for BI0, BI1, and BI2 from right wrist-worn activity monitors at light, moderate, and vigorous physical activity intensities.

LIGHT		BI0	BI1	BI2
	Mean	31.4	32.0	32.4
	SD	1.5	1.5	1.2
	SE	1.1	1.1	1.1
	L 95 CI	25.1	25.6	26.1
	H 95 CI	39.4	39.8	40.2
MODERATE		BI0	BI1	BI2
	Mean	145.3	145.9	146.5
	SD	1.4	1.4	1.4
	SE	1.1	1.1	1.1
	L 95 CI	119.2	119.7	120.3
	H 95 CI	177.3	177.9	178.5
VIGOROUS		BI0	BI1	BI2
	Mean	466.9	469.3	472.1
	SD	1.2	1.2	1.2
	SE	1.0	1.0	1.0
	L 95 CI	426.2	428.3	430.7
	H 95 CI	511.4	514.5	517.5

Note: values are in kcals; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C5. Summary of predicted activity energy expenditure (AEE_P) for BI0, BI1, and BI2 from left wrist-worn activity monitors at light, moderate, and vigorous physical activity intensities.

LIGHT		BI0	BI1	BI2
	Mean	36.0	36.6	37.1
	SD	1.4	1.3	1.4
	SE	1.1	1.1	1.1
	L 95 CI	30.3	31.0	31.4
	H 95 CI	42.6	43.2	43.9
MODERATE	Mean	140.0	140.5	141.2
	SD	1.5	1.5	1.5
	SE	1.1	1.1	1.1
	L 95 CI	110.4	111.0	111.7
	H 95 CI	177.0	177.7	178.4
VIGOROUS	Mean	463.1	465.8	468.9
	SD	1.2	1.2	1.2
	SE	1.0	1.0	1.0
	L 95 CI	421.5	423.7	426.7
	H 95 CI	508.9	512.0	515.3

Note: values are in kcals; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C6. Summary of actual time spent at or above a moderate intensity for BI0, BI1, and BI2 at light, moderate, and vigorous physical activity intensities.

	BI0	BI1	BI2
Mean	36.4	39.0	42.3
SD	4.8	5.7	6.0
SE	1.2	1.5	1.6
L 95 CI	33.7	35.8	39.0
H 95 CI	39.1	42.2	45.7

Note: values are in mins; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C7. Summary of predicted time spent at or above a moderate intensity for BI0, BI1, and BI2 from right hip-worn activity monitors at light, moderate, and vigorous physical activity intensities.

	BI0	BI1	BI2
Mean	49.5	52.4	58.4
SD	2.7	2.8	1.5
SE	0.7	0.7	0.4
L 95 CI	48.0	50.9	57.5
H 95 CI	51.0	53.9	59.3

Note: values are in mins; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C8. Summary of predicted time spent at or above a moderate intensity for BI0, BI1, and BI2 from left hip-worn activity monitors at light, moderate, and vigorous physical activity intensities.

	BI0	BI1	BI2
Mean	50.3	53.5	57.9
SD	2.6	2.4	2.3
SE	0.7	0.7	0.6
L 95 CI	48.8	52.0	56.7
H 95 CI	51.7	54.9	59.2

Note: values are in mins; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C9. Summary of predicted time spent at or above a moderate intensity for BI0, BI1, and BI2 from right wrist-worn activity monitors at light, moderate, and vigorous physical activity intensities.

	BI0	BI1	BI2
Mean	41.4	44.1	49.2
SD	6.1	6.4	7.4
SE	1.6	1.6	1.9
L 95 CI	38.0	40.6	45.1
H 95 CI	44.8	47.7	53.3

Note: values are in mins; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.

Table C10. Summary of predicted time spent at or above a moderate intensity for BI0, BI1, and BI2 from left wrist-worn activity monitors at light, moderate, and vigorous physical activity intensities.

	BI0	BI1	BI2
Mean	43.1	45.9	51.6
SD	5.2	5.8	7.5
SE	1.4	1.5	1.9
L 95 CI	40.2	42.6	47.4
H 95 CI	46.1	49.1	55.8

Note: values are in mins; BI0 = No bout interruption; BI1 = 1-min bout interruption; BI2 = 2-min bout interruption; SE = standard error, L 95 CI = lowest value from a 95% confidence interval; H 95 CI = highest value from a 95% confidence interval.