

A COMPARISON OF BILATERALLY WRIST-WORN ACCELEROMETERS ON
MEASURES OF FREE-LIVING PHYSICAL ACTIVITY IN ADOLESCENTS

by

Edward Moises Davila

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Health and Human Development

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2011

©COPYRIGHT

by

Edward Moises Davila

2011

All Rights Reserved

APPROVAL

of a thesis submitted by

Edward Moises Davila

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

Dr. Daniel P. Heil

Approved for the Department of Health and Human Development

Dr. Mark D. Nelson

Approved for The Graduate School

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Edward Moises Davila

May 2011

TABLE OF CONTENTS

1. INTRODUCTION	1
Measurement and Placement of Activity Monitors	3
Statement of the Problem.....	6
Primary Hypothesis.....	6
Delimitations.....	7
Limitations	7
Assumptions.....	7
Operational Definitions.....	8
2. REVIEW OF THE LITERATURE	9
Introduction.....	9
Methods of Measuring Physical Activity	10
Activity Monitor Considerations	15
Standardization of Data Handling.....	18
Activity Monitor Placement.....	21
3. THESIS MANUSCRIPT	24
Introduction.....	24
Methodology	28
Pre-Collection Phase	28
Subjects	28
Study Protocol.....	28
Instrumentation	29
Collection Phase.....	29
Post-Collection Phase	30
Quality and Quantity Control Checks.....	30
Data Transformations.....	31
Statistical Analysis.....	32
Results.....	33
Single Regression Calibration Algorithm	34
Double Regression Calibration Algorithm	34
Subgroup Analyses	40
Discussion	43
Between Bout Differences	46
Omitted Data.....	47
Compliance	47
Conclusion	48

TABLE OF CONTENTS – CONTINUED

4. CONCLUSIONS.....	49
REFERENCES	51
APPENDIX A: Subject Consent Form	56

LIST OF TABLES

Table	Page
2.1. Accelerometer count cut points defining exercise intensity	19
3.1. Summarized outline of study protocol	30
3.2. Summary of single (1R) and double (2R) regression algorithms for converting raw activity monitor output to activity energy expenditure (AEE) in children 8-17 years of age at the wrist location (Heil 2006)	32
3.3. Demographic characteristics of all participants	36
3.4. Subject demographics by gender	36
3.5. Summarized data for activity counts (AC) in light physical activity intensity using the 2R algorithm	37
3.6. Summarized data for activity counts (AC) in moderate-to-vigorous physical activity intensity using the 2R algorithm	37
3.7. Summarized data for activity energy expenditure (AEE) in light physical activity intensity using the 2R algorithm	37
3.8. Summarized data for activity energy expenditure (AEE) in moderate-to-vigorous physical activity intensity using the 2R algorithm	38
3.9. Summarized data for duration of time (T) in light physical activity intensity using the 2R algorithm	38
3.10. Summarized data for duration of time (T) in moderate-to-vigorous physical activity intensity using the 2R algorithm	38
3.11. Duration of time (T) spent within moderate-to-vigorous intensity for all bouts from dominant and non-dominant activity monitors separated by gender	42

LIST OF TABLES – CONTINUED

Table	Page
3.12. Duration of time (T) spent within moderate-to-vigorous intensity for all bouts form left and right wrist activity monitors separated gender	42

LIST OF FIGURES

Figure	Page
3.1. Systematic diagram of Pre-Collection, Collection, and Post-Collection Phases.....	35
3.2. Relationship between duration of time spent in moderate-to-vigorous physical activity intensity for all bout durations between dominant (D) and non-dominant (ND) activity monitors.....	39
3.3. Relationship between duration of time spent in moderate-to-vigorous physical activity intensity for all bout durations between left (L) and right (R) wrist activity monitors	40

ABSTRACT

With the advancement of technology, the use of accelerometry-based wrist-worn activity monitors (AM) to measure free-living physical activity (PA) has become extremely popular. Whereas the influence of contralateral wrist AM placement has been evaluated in adults, no research has investigated the influence of wrist-worn AM location (dominant [D] versus non-dominant [ND] or left [LW] versus right [RW]) on measurements of free-living PA in adolescents. **Purpose:** The purpose of the current study was to evaluate the influence of wrist-worn AM wear location (D versus ND and LW versus RW) and AM processing algorithm (single (1R) versus double (2R) regression) on measures of free-living PA in adolescents 12-17 years of age. **Methods:** Eight boys (Mean $\pm$ SD: 14.3 $\pm$ 1.9 yrs, 53.9 $\pm$ 13.6 kg, 160.5 $\pm$ 14.5 cm, 20.6 $\pm$ 2.3 body mass index [BMI]) and 12 girls (13.9 $\pm$ 1.6 yrs, 56.1 $\pm$ 9.9 kg, 160.3 $\pm$ 7.4 cm, 21.4 $\pm$ 2.6 BMI) participated in the study. Each subject wore two AMs for 7 consecutive days (24 hr/day), with one AM attached to the dorsal side of each wrist using locking plastic wrist bands. Subjects were instructed to engage in their usual daily activities. After downloading the raw AM data to a computer, previously validated algorithms (1R and 2R) were used to transform and summarize the data into counts (counts/day), activity energy expenditure (AEE; kcals/day), and duration of time (T; minutes/day) for 1, 5, and 10 minute bout durations within light (L) and moderate-to-vigorous (MV) intensity categories for AMs (D, ND and for LW, RW). Dependent variables (CNT, AEE, T) were compared using two-factor multivariate repeated measures ANOVA ($\alpha=0.05$) for data processed by both algorithms separately. Scheffe's post-hoc analyses ($\alpha=0.01$) were performed for all pairwise comparisons when indicated by the ANOVA. **Results:** No significant differences existed between mean values for dependent variables for any bout duration within L or MVPA intensity between monitors (D versus ND or between LW versus RW) or processing algorithm. **Conclusion:** These data indicate that wrist-worn AM location has no significant influence on PA outcome variables in adolescent under free-living conditions. Researchers can now allow participants the freedom to choose which wrist they would prefer the monitor be placed when being assessed.

CHAPTER 1

INTRODUCTION

Improving techniques for the assessment of physical activity (PA) is one of the top research priorities for the exercise science field. An accurate assessment of PA is necessary to more objectively evaluate the health benefits associated with habitual PA and the effectiveness of behavioral interventions designed to promote PA (Welk, Blair, Wood, Jones, and Thompson 2000). As in adults, habitual PA in children is important for health and well-being. Furthermore, habitual PA behaviors in childhood are likely to transition into adulthood. Participation in daily PA becomes critically important in the prevention of hypokinetic diseases and has been associated with reduced mortality, morbidity, and better health, particularly with advancing age (Egerton and Brauer 2009; Paffenbarger et al. 1994). Hypokinetic diseases are conditions that arise from a sedentary lifestyle such as cardiovascular disease (CVD), obesity, and type 2 diabetes mellitus. Reliable estimates of daily PA for children and adolescents are therefore required to develop appropriate PA promotional strategies.

Physical activity is characterized as any bodily movement produced by the contraction of skeletal muscle that considerably increases energy expenditure (EE) above the basal level (Caspersen, Powell and Christenson 1985). In 2008, the U.S. Department of Health and Human Services (USDHHS) released the first comprehensive PA guidelines ever issued by the Federal Government. The guidelines state that children and adolescents should accumulate at least 60 minutes or more of moderate to vigorous

intensity aerobic activity daily as well as vigorous-intensity PA at least three days a week. Furthermore, children and adolescents should include both muscle and bone-strengthening PA on at least three days of the week as a part of their 60 or more minutes of PA. The modality of PA should also be age appropriate, provide variation and be enjoyable.

Prior to the USDHSS (2008) guidelines, consensus PA recommendations for children and adolescents were lacking. With no standardized PA guidelines for children, the provisional recommendations across the U.S were primarily subjective. Consequently, prescribed PA may have contained considerable variation, with many children and adolescents participating in PA far below the minimum requirements to maintain good health. Sisson, Broyles, Baker, and Katzmarzyk (2010) reported 47% of U.S. youth in 2003 spent more than 2 hours in daily screen-based (television, video, computer) leisure time sedentary behaviors (LTSB). Since 1980, the prevalence of child and adolescent obesity has tripled (Ogden et al. 2006) and has been associated with metabolic health risks, chronic diseases, psychosocial problems and an increased risk of CVD in adulthood (Ebbeling, Pawlakk, and Ludwig 2002; Baker, Olsen, and Sorensen 2007). Moreover, trends in PA typically decline with increasing age predominately during puberty and especially for females (Sherar et al. 2009; ACSM 2006). Thus, researchers need effective PA assessment strategies to study free-living PA patterns in children and adolescents.

Measurement and Placement of Activity Monitors

Recent technological advances in objective PA assessment have created the opportunity for researchers to describe ambulatory PA using nonobtrusive motion sensors (Behrens and Dinger 2007). Accelerometry-based activity monitors (AMs), in particular, can provide information about the amount, frequency, and duration of PA (Plasqui and Westerterp 2007). These portable AMs are designed to detect and record bodily accelerations. Most AMs contain one or multiple piezoelectric acceleration sensors, each of which consists of an element and a seismic mass. When accelerated, the seismic mass causes the piezoelectric element to deform, which causes a voltage output proportional to the applied acceleration. The piezoelectric sensor within uniaxial AMs are most sensitive within the vertical dimension. However, other piezoelectric sensors can detect acceleration in multiple dimensions such as vertical, horizontal and lateral axes, with vertical being the most sensitive (Chen and Bassett 2005). In contrast, triaxial AMs measure acceleration in three dimensions, providing output for each dimension separately, as well as a composite measure (Rowlands 2007). The generated bidirectional voltage signals are then amplified and passed into an analog to digital (A/D) converter within a microrepressor to create a digital value termed “raw counts,” anywhere from 1 to 64 times per second (64Hz). These values are then summed over a specific user-defined time interval (epoch) between 0.25 and 1 minute (Chen and Bassett 2005). The resulting “raw” data from the activity monitors can be reported, via validated algorithms, as independent measures of physical activity, minutes spent in physical activity of different intensities, and/ or converted into estimates of EE (Paul, Kramer, Moshfegh, Baer, and

Rumpler 2007).

Generally worn at the wrist or hip, AMs have become exceedingly popular for measuring free-living PA in children. When positioned at the waistline (i.e., hip-worn monitors), the AM is most sensitive to vertical movements of the torso and thus describes measurements of whole-body PA. In adults however, the hip-worn AM location has been associated with considerable compliance issues. The most acknowledged problems that arise when participants are asked to wear AMs at the hip are donning and doffing of the device at various times throughout the monitoring period. In addition, subjects not wearing the monitor on a given day, or forgetting to replace the monitor after a temporary removal are also commonly observed issues at the hip-worn location (Heil, Bennett, Bond, Webster, and Wolin 2009). In response to these compliance issues, alternative AM placement sites such as the wrist and ankle (Heil 2006) have been investigated.

Participant AM wearing compliance and monitor placement are just a few practical issues to consider when assessing free-living PA of children. Where wrist AM placement may abate compliance issues commonly observed with hip-worn placement, the impact of AM placement on the wrists is still unclear. For example, should participants be allowed to choose which wrist to wear an AM? The convenience of user-preferred wrist AM placement in adolescents could attenuate noncompliance while enhancing their willingness to wear the AM. User-preferred placement of wrist-worn AMs may consequently allow for more reliable estimates of PA in children and adolescents under free-living conditions.

The only study known to investigate the impact wrist-worn AM placement was performed by Hornbuckle, Whitt-Glover and Heil (2010) in young adults (Mean $\pm$ SD: 22.3 $\pm$ 3 yrs). The authors concluded that there was no significant difference between measures from the left and right wrist-worn AMs. As a result, researchers can now allow young adults the freedom to choose which wrist they prefer the monitor to be placed. To date, however, no studies have evaluated the impact of wrist-worn AM location (left or right wrist; dominant or non-dominant) on the measurement of free-living PA related variables in children or adolescents.

The outcome of wrist-worn AMs placement (dominant vs. non-dominant) on measurements of free-living PA in children and adolescents is a very important methodological issue to consider for researchers. Besides compliance problems, another issue to contemplate is comfort. The level of comfort, in turn, may directly influence the degree of subject compliance. When participants are asked to wear AMs on the wrist, the experience of wearing the device itself must not become a burden. Subject comfort becomes critically important when attempting to measure free-living PA patterns in children and adolescents using wrist-worn AMs where the highest level of conformity is desired. By allowing participants to actively choose which wrist, dominant or non-dominant, they would prefer the monitor to be placed may put the researcher in the best position to capture the most reliable representation of a child's or adolescent's free-living PA patterns.

Statement of the Problem

The purpose of this study was to determine the influence of wearing AMs on the dominant versus non-dominant wrists on measurements of free-living PA in adolescents ages 12-17 years old.

Primary Hypothesis

The null hypothesis was that summarized AM data expressed as total counts (counts/day), activity energy expenditure (AEE; kcals/day), and duration of time (Time; minutes/day) spent within categories of light (L) and moderate-to-vigorous (MV) activity intensities within PA bouts lasting 1, 5, and 10 minutes in duration for both wrist-worn monitors (dominant and non-dominant) would be equal.

$$H_0: \mu_{CNT(D)} = \mu_{CNT(ND)}, \mu_{AEE(D)} = \mu_{AEE(ND)}, \mu_{T(D)} = \mu_{T(ND)}$$

$$H_A: \mu_{CNT(D)} \neq \mu_{CNT(ND)}, \mu_{AEE(D)} \neq \mu_{AEE(ND)}, \mu_{T(D)} \neq \mu_{T(ND)}$$

Where $\mu_{CNT(D)}$ and $\mu_{CNT(ND)}$ = total counts measured from both the dominant (D) and non-dominant (ND) wrist-worn monitors, $\mu_{AEE(D)}$ and $\mu_{AEE(ND)}$ = AEE from both D and ND wrist-worn AMs, and $\mu_{T(D)}$ and $\mu_{T(ND)}$ = actual time spent in L, and MV activity intensities for both D and ND wrist-worn AMs.

Delimitations

1. The subject population was delimited to adolescents located in Bozeman, MT.
2. The subject population was delimited to adolescents ages 12-17 years of age.

Limitations

1. Accelerometers may under detect the full energy cost of certain activities such as carrying an external load up a flight of stairs.
2. The calibration algorithms used in the current study to convert raw activity monitor data into physiologically meaningful units are specific to the brand of AM used, wearing location, and population from which the algorithm was originally derived.

Assumptions

1. It was assumed that the Actical® monitor was a reliable instrument for measuring physical activity (PA).
2. It was assumed that the wrist was a viable location for wearing the Actical® monitor when assessing PA of children.

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 given task.
Activity Energy Expenditure (AEE):	Relative energy expenditure to perform a given task above resting metabolic rate (kcal/kg/min or kcal/day).
Total Energy Expenditure (TEE):	Relative energy expended on average, during a single day (24hrs/day).
Physical Activity (PA):	Any bodily movement produced by the contraction of skeletal muscle and that substantially increases energy expenditure above the basal level.
Physical Activity Intensity:	The EE or MET level of a particular activity.
Physical Activity Duration:	The time (min) spent engaged in an activity.
Metabolic Equivalent (MET):	A unit describing the resting metabolic rate while sitting quietly in a chair. One MET is approximately equal to an oxygen consumption of 3.5 ml/kg/min. Intensity of exercise is expressed as multiples of METs.
Activity Monitor (AM):	An accelerometry-based device used to detect bodily accelerations and record consequent energy expenditure.
Dominant Hand (DH):	Subject's preferred hand for writing.
Monitoring Day:	Period of time lasting at least 24 consecutive hours where physical activity is measured with an accelerometer.

CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

Habitual physical activity (PA) has been suggested to reduce the risk of premature mortality, morbidity, and enhance overall health (Paffenbarger et al. 1994). Some of the physiological benefits associated with daily PA in adolescents include reduced low density lipoprotein (LDL), improved high density lipoprotein (HDL), improved bone strength, muscle strength, self image and self esteem.

Although well known health benefits have been associated with habitual PA, in the U.S. alone child and adolescent obesity rates have tripled since 1980 (Ogden et al. 2006). Being considered overweight during childhood substantially increases the chances of becoming obese in adulthood (Cobayashi et al. 2010). A study conducted by Deshmukh-Taskar et al. (2006) measured and tracked BMI in a single group of children ages 9 to 11 and then again from 19 to 35 years of age. The authors concluded that 61.9% of the 841 individuals tracked from childhood to adulthood, remained in the last BMI quartile. Furthermore, a sedentary and obese lifestyle has been linked to metabolic health risks, chronic diseases, psychosocial problems and an increased risk of cardiovascular disease (CVD) in adulthood (Ebbeling et al. 2002; Baker et al. 2007).

In response to the prevalence of child and adolescent obesity and its negative influence on health status, many techniques have been developed in an attempt to capture reliable estimates of PA under both lab- and field-based conditions. Improving techniques

for the assessment of PA is one of the top research priorities for the exercise science field. An accurate assessment of PA is necessary to more objectively evaluate the health benefits associated with PA and the effectiveness of behavioral interventions designed to promote PA (Welk et al. 2000). Due to technological advances, the measurement of field based or free-living PA patterns in adolescents has become exceedingly popular.

There are four domains researchers must consider when attempting to gather estimates of PA in adolescents. Those domains are duration, frequency, intensity, and mode of PA. All of the subsequent health benefits engendered by daily PA are influenced by these four aspects of PA. The measurement of frequency, duration and mode of PA are relatively easy to obtain. Intensity of PA however, is much more challenging to capture, particularly under free-living conditions. Although sometimes challenging to measure, energy expenditure (EE) has been used as a common physiological maker to describe intensity of PA. In adolescents, an important consideration is the variability of basal metabolic rate (BMR) and resting metabolic rate (RMR). Due to the variation in age range, biological maturation, compositional makeup, and level of PA, a more practical physiological unit of output is used for predicting EE, is activity energy expenditure (AEE). Activity energy expenditure is defined as the relative EE (kcal/kg/min) required to perform a task above that of resting metabolism (Heil, 2006).

Methods of Measuring Physical Activity

Numerous studies have been conducted to determine acceptable methods for assessing free-living PA (Eston, Rowlands, and Ingledew 1998; Ekelund et al. 2001;

Matthews, Ainsworth, Thompson, and Bassett 2002; Heil 2009; Sinard and Slater 2009; Hornbuckle et al. 2010). There are several techniques that attempt to describe PA by estimating EE. For example, direct calorimetry (DC), which is the most accurate measure of EE with estimates of less than $\pm 1\%$ error, is a lab-based technique used to measure EE. Direct calorimetry requires a specialized chamber that measures heat produced by the body via conduction, convection, and evaporation. The resulting temperature differentiation in the air and water flowing through and around the chamber is a direct representation of the subject's metabolic rate. Due to the instrumentation required for DC however, the utilization of this technique is confined to lab-based measures of EE and thus not ideal for free-living measures of PA.

Similarly, indirect calorimetry (IC) measures the consumption of inspired oxygen and has been positively correlated with heat production with an error of approximately $\pm 2-3\%$ (Laporte, Montoye, and Caspersen 1985). Whereas DC measures heat production directly, IC measures the respiratory gas exchange of oxygen (O_2) and carbon dioxide (CO_2). Furthermore, IC possesses the capabilities to measure EE under both lab- and field-based conditions. Indirect calorimetry has some notable limitations such as the need to wear a metabolic system which alters or inhibits normal PA patterns and is not ideal for measuring for extended periods of time. Also, IC requires a steady-state heart rate, which under free-living conditions, are atypical (Welk 2005). Although extremely accurate, both DC and IC are not practical for free-living measurements of EE as they both modify or restrict normal free-living PA patterns (Laporte et al. 1985).

Another method for measuring EE is the doubly labeled water (DLW) technique,

developed by Lifson, Gordon, and McClintock (1955). Doubly labeled water is considered the “gold standard” measure of PA. This technique requires subjects to orally ingest water containing isotopically labeled hydrogen (H^+) and O_2 atoms. The relative proportions of water utilized for metabolic energy and water not utilized provides estimates of total energy expenditure (TEE) (Laporte et al. 1985) as measured by excreted urine samples. This technique can measure TEE anywhere from one to three weeks (Ekelund et al. 2001). Although DLW does not compromise normal patterns of free-living PA, it estimates overall caloric expenditure only and thus cannot distinguish between patterns of PA (Laporte et al. 1985).

Alternative techniques have been developed and used for assessing PA under free-living conditions. Methods of measurement such as heart rate monitoring, pedometers, self-report, and accelerometry-based activity monitors (AMs), are noninvasive methods that do not impose any restrictions on typical PA patterns. Heart rate monitoring is another method used for the assessment of PA. A heart rate monitor is a device worn around the chest with the transmitter placed directly over the xiphoid process. Usually, an adjustable band circumvents the chest at the level of the xiphoid process to keep the transmitter and electrodes in contact with the skin during ambulation. Heart rate monitors are designed to measure heart rate continuously over an extended period of time (Laporte et al. 1985). Although not measuring PA directly, this method is based on the linear relationship between oxygen consumption (VO_2) and heart rate. During activity, as VO_2 increases in response to an increase in intensity and duration, heart rate increases proportionally. Some limiting factors of this techniques however, are

psychological influences such as emotional stress which can elevate heart rate independently of any change in VO_2 (Eston et al. 1998). In addition, estimating EE using heart rate monitoring may be more practical during PA of higher intensity due to the weak relationship between VO_2 and heart rate at rest (Laporte et al. 1985).

An alternative method for measuring PA is through the use of pedometers. Pedometers are relatively small motion sensors, generally worn at the hip, and are used to count steps during moments of ambulation. Researchers have used pedometers to describe PA patterns with great accuracy (Schneider, Crouter, and Bassett 2004). Pedometers provide an inexpensive, accurate, reliable, and objective measure of ambulation (Clemes and Parker 2009) and are relatively easy to administer to large populations to measure PA under free-living conditions. However, a noteworthy limitation to pedometry is that most pedometers are unable to assess intensity, frequency or duration of PA. Additionally, pedometers are incapable of accurately measuring nonambulatory activities such as cycling or arm ergometry (Corder, Brage and Ekelund 2007). Furthermore, a study by Melanson et al. (2004) concluded that below ambulation speeds of 3 km/hr (1.86 mph), pedometer accuracy is substantially diminished.

Self-reporting, which consists of individuals manually recording their daily PA, is a technique commonly utilized by researchers assessing PA. Physical activity diaries, typically used a form of self-reporting, acts as a log for participants to record daily PA. Due to the ease of administering this technique and the fact that it can provide information on the types of activities performed, self-report measures are extremely advantageous in large-scale studies. In contrast, some disadvantages to using self-report

measures are time commitments for manually recording PA and cognitive reliability (e.g. being able to accurately recall and describe previous PA bouts). There have been numerous studies describing the sources of variance (Baranowski et al. 1999; Matthews et al. 2001) such as overestimating and/or underestimating PA level, that have been associated with self-report measures of PA. From children to adults, inaccurate measures of PA via self-report have been well documented (Washburn 2000; Sallis and Saelens 2000). Moreover, Rikli (2000) suggested that recall bias, fluctuations in health, mood, depression, or anxiety may be confounding factors influencing said variability during self-report measures of PA.

Due to the lack of accuracy from self-report methods, objective methods such as motion sensors have been developed (Ekelund et al. 2001). Technological advances in objective PA assessment have created the opportunity for researchers to describe free-living ambulatory PA using nonobtrusive motion sensor devices (Behrens and Dinger 2007). An exceedingly popular technique for measuring free-living EE is through usage of accelerometry-based activity monitors (AMs), which are designed to detect and measure bodily accelerations. Typically worn at the hip or wrist, AMs are small, lightweight, noninvasive instruments that quantify the intensity of movements by measuring a change in velocity with respect to time (m/s^2).

Most AMs house one or more piezoelectric accelerometers, each of which consists of a piezoelectric element and a seismic mass. When the seismic mass experiences acceleration, there is a corresponding degree of bending in the element. This deformation causes a voltage output proportional to the acceleration experienced by the

AM. These output values are then summed over a specific user-defined interval (epoch) between 0.25 and 1 minute (Chen and Bassett 2005). The resulting “raw” data can then be converted to physiologically meaningful units such as independent measures of PA, minutes spent in PA of different intensities, and/or converted to estimates of EE (Paul et al. 2007).

Activity Monitor Considerations

As AMs are the most technologically advanced measure of free-living PA, there are many considerations researchers must acknowledge when attempting to use these utilize these devices. Some of these considerations are: number of axes, epoch length, monitor wearing duration, and monitor calibration.

When using AMs, it is important to choose an AM that is most applicable to the question(s) at hand. There are three types of AMs (uniaxial, triaxial, and omnidirectional) that are used to estimate EE. A review by Trost et al. (2005) concluded that there was no compelling evidence suggesting superior validity or reliability of one monitor over the other. Uniaxial AMs are most sensitive in the vertical dimension. When positioned at the hip, closes to the body’s center of gravity (COG), the uniaxial AM is most sensitive to the natural oscillation of the COG during ambulation and thus reliable measures of whole-body EE. However, due to the lack of accelerometer sensitivity, one limitation with uniaxial AMs is its inability to capture energy costs of running at high speeds. A study by Rowlands, Stone, and Eston (2007) concluded in adults, uniaxial AMs failed to accurately measure EE at running speeds greater than 10 km/hr (6.21 mph). Triaxial AMs

consist of three orthogonal accelerometer units that can measure acceleration in three planes separately, providing data for each plane, as well as providing a composite measure (Rowlands 2007). Theoretically, a triaxial monitor is advantageous because of its ability to detect accelerations in three-dimensional space. However, direct evidence for triaxial AM superiority over uniaxial has yet to be established (Freedson, Pober, and Janz 2005). Similar to the triaxial AM, omnidirectional AMs can measure acceleration not only within the axis of bending (e.g., vertical to ground), but also in other dimensions such as mediolateral and anteroposterior (Chen and Bassett 2005; Eston et al. 1998).

Another important consideration when using AMs is determining epoch length. An epoch is a user-defined interval over which output values are summed. The optimum epoch length to capture most variation in PA per accelerometry relies heavily on population age (Corder et al. 2007). For example, in adults, traditional epoch length for EE has been 60 seconds. A 60-second epoch directly reflects the standard 60-second sample interval used to measure steady-state oxygen consumption (VO_2) during indirect calorimetry (IC) (Heil, Brage, and Rothney In press). In contrast, researchers assessing PA in children are using shorter AM epochs, such as 15 s or less, to capture the sporadic bouts of vigorous intensity (Baquet et al. 2007).

In 1995, Bailey and colleagues conducted an observational study attempting to evaluate the “tempo” of PA patterns in children under free-living conditions. The investigators found that low to medium intensity bouts of PA lasted an average of 6 seconds, whereas high intensity PA lasted less than 3 seconds. When selecting epoch length it is important to consider the general activity patterns of the population of interest.

Selecting an epoch is also important with regards to different AM internal methods of measurement. For example, the most commonly used triaxial AM only offers 1 or 60 seconds epochs. Considering the transient PA behavior of children, the triaxial AM may drastically overestimate and/or underestimate EE due to the absence of shorter interval options such as 5, 10, or 15 seconds epochs.

Monitor wearing duration is another concern for researches to address. There are various methodologies on the number of days of AM wear required for a reliable estimate of habitual PA (Corder et al. 2007). A review article by Trost et al. (2005) found that in adults, 3-4 days of AM wear were required to achieve an intraclass correlation coefficient (ICC) of 0.80, whereas at least 7 days of wear were necessary to reliably estimate patterns of inactivity. Matthews et al. (2002) in addition, stated that weekend PA in adults, when compared to weekday PA, was significantly lower on Saturday and Sunday with the former being the more active. In children, Trost and colleagues (2005) concluded that 4-5 days of AM wear was required to achieve a reliability of 0.80 whereas 8-9 days were required to achieve a reliability of 0.80 in adolescents. The amount of AM wear time must be sufficient in order to represent behavioral reliability which, according to Heil et al. (In press), refers to the minimum number of days that AMs should be worn such that daily averages for PA outcome variables accurately reflect habitual PA.

Monitor calibration is another vital component for researcher to consider when using AMs. Recorded “raw” data from the AMs can be used to answer minor questions. However, more recent studies prefer the raw data be converted into more physiologically meaningful units (Ward et al. 2005). These calibrations, in turn, are typically used to

transform raw AM data into predicted EE, or to identify activity type (Heil et al. In press). Regardless of the calibration method, if activity type is not taken into account to begin with, subsequent errors in predicting EE will ensue (Rowlands 2007). Moreover, each calibration algorithm is specific to each brand of AM, the population from which the algorithm was originally validated, and the wearing location (Heil et al. In press). For example, Heil et al. (2009) evaluated how time (T_{MV} , min/day), EE (AEE_{MV} , kcal/day) and movement count-based (CNT_{MV} , counts/day) PA outcome variables would vary between different AM locations (ankle, hip, wrist) under free-living conditions. The authors concluded that during smaller bout durations ($<3-4$ minutes), absolute differences among PA outcome variables were greater across monitor locations when compared to longer bout durations ($\geq 8-10$ minutes). Therefore, wearing location alone influences AM outcome variables. The subsequent algorithms used to covert raw AM output data into more meaningful units should be specific to that AM location. Thus, it is not ideal to use a single algorithm to estimate EE for all types of activities, on multiple populations, or from multiple AM wearing locations. The task falls solely on the user to determine which algorithms are appropriate for his or her research objectives (Heil et al. In press).

Standardization of Data Handling

One of the most challenging aspects of using AMs to measure PA is managing and understanding the vast amounts of data collected. With AM wearing recommendations of 3-9 days (Troost et al. 2005), and sampling epochs as low as 15 seconds, the volume of data produced by AMs can be immense (Ward et al. 2005). While

the use of AMs has become exceeding popular within the last decade, there currently is no standardized protocol for the collecting, processing, and reporting of PA outcome variables as measured by AMs. Making decisions about how to clean, collapse, and analyze data prior to collection was one of the many recommendations Ward et al. (2005) suggested for future studies regarding AMs usage.

The raw data, commonly referred to as *accelerometer counts*, are a dimensionless summarized measure of acceleration (Rowlands 2007). How researchers handle this data can vary and as a result, produce ambiguous values for the same outcome variables. These accelerometer counts are typically expressed as specific biological units such as EE or AEE. This, in turn, has resulted in the publication of numerous count thresholds established to describe various categories of EE (Rowland 2007).

Freedson et al. (2005) in a review, highlighted the calibration of four different AMs used to assess PA and sedentary behavior in children. Specifically, the authors compared varied ranges of accelerometer counts (cut points) corresponding to predetermined intensity levels (Table 2.1).

Table 2.1. Accelerometer count cut points defining exercise intensities.

Authors	Sample Size	Age or Age Range (yr)	Monitor	Activities	Criterion	Mod Cut Points (counts/ min)	Vig Cut Points (count/ min)
McMurray et al. (2004)	308	8-18.0	Tritrac	W, R, FL	$\dot{V}O_2$	>400	<2200
Eston et al. (1998)	30	8.2-10.8	Tritrac	W, R, FL	$\dot{V}O_2$	>300	<2200
Rowlands et al. (2004)	19	9.5	Tritrac	W, R, FL	$\dot{V}O_2$	>770	<1870
Rowlands et al. (2004)	19	9.5	RT3	W, R, FL	$\dot{V}O_2$	>970	<2333
Treuth et al. (2004)	74	13-14	Actigraph	W, R, FL	$\dot{V}O_2$	>3000	<5200
Puyau et al. (2000)	26	6-16.0	Actigraph	W, R, FL	EE	>3200	<8200
Eston et al. (1998)	30	8.2-10.8	Actigraph	W, R, FL	$\dot{V}O_2$	>500	<4000
Puyau et al. (2004)	32	7-18.0	Actical	W, R, FL	EE	>1500	<6500

These ranges of cut points or thresholds in Table 1 correspond to a specific predefined intensity level such as moderate or vigorous intensity PA. The authors concluded that for a given accelerometer, there was a significant difference among the articles reviewed, for predetermined thresholds defining boundaries for 3 and 6 metabolic equivalents (METs). The number of thresholds reviewed highlights the lack of agreement with regards to the interpretation of accelerometer output (Rowlands 2007).

Another study exploiting the lack of agreement and variability regarding the handling of accelerometer output data was performed by Masse et al. (2005). The purpose of the study was to examine the impact of varying certain decision rules for the handling of accelerometer output data. The investigators sought to assess quantitatively the impact of using four different algorithms to analyze the same data set. The authors concluded that the use of different algorithms impacted several important outcome variables. Furthermore, with multiple handling techniques for AM output data, there are significant impacts on important outcome variables. With no consensus guidelines, it remains difficult to compare findings across studies.

In response to ambiguous handling techniques of AM output data, numerous studies (Ward et al. 2005; Heil et al. In press) have brought forth best practice recommendations for handling such data. Ward et al. (2005) presented the best practices for researchers on five general topics of accelerometer use. The topics covered were 1) Monitor selection, quality, and dependability; 2) Monitor use protocols; 3) Monitor calibration; 4) Analysis of accelerometer data; and 5) Integration with other data source. The authors suggested that researchers attempt to integrate these practices into their AM

handling schemes.

Similarly, Heil et al. (In press), suggested best practices to establish a universal systematic approach for handling AM output data. Specifically, the authors presented The Standard 7-Step Algorithm, which according to the authors, was a series of functional and analytical steps used to predict PA outcome variables with AMs. The steps, in order were: 1) Defining the Data Collection Strategy; 2) Instrumentation Selection and Protocol Design; 3) On-Board Biosignal Processing; 4) Immediate Data Processing; 5) Data Transformation; 6) Data Summarization Characteristics; and 7) Generation of PA Outcome Variables. The authors suggested these guidelines be used as a starting-point for new studies. In addition, this systematic construct for handling AM output data helps establish a standardized protocol for future researchers using AMs. With a standardized method for handling AM data, objective measures for assessing free-living PA may contain less variability and thus be more practical to compare across studies.

Activity Monitor Placement

The relative positioning of the AMs on the body is another important consideration for researchers (Troost et al. 2005). Numerous studies have used various AM wearing locations such as the hip, ankle, wrist, or low back to assess lab-based and/or field-based measures of PA (Heil 2006; Ekelund et al. 2001; Matthews et al. 2002; Pfeiffer et al. 2006; Heil et al. 2009, Hornbuckle et al. 2010; Kolle, Steene-Johannessen, Anderson, and Anderson 2010). The most common placement of AMs is along the beltline just anterior to the iliac crest of the hip. In a review by Troost et al. (2005), the

authors concluded that AM are best placed on the hip or the low back when assessing PA. Although the hip location offers a theoretical advantage (measuring acceleration near the subject's center-of-mass), subject compliance has historically been poor (Heil et al. In press). As a result, alternative AM wear locations, such as the ankle and wrist, have been suggested (Heil 2006) and utilized (Heil et al. 2009) to measure free-living PA.

Compliance issues and AM placement are important considerations for researchers using accelerometer devices. Depending on the population of interest and activity type, certain AM placement sites may be more ideal than others. For example, due to the well-known compliance issues associated with hip-worn AMs, the wrist may be a more feasible location for measuring free-living PA in adolescents. Where wrist-worn AM placement may reduce compliance issues commonly observed with hip-worn AM placement, the impact of AM placement on the wrists themselves has yet to be evaluated in adolescents.

Currently, the only study known to investigate the influence of wrist-worn AM placement (left vs. right, dominant or non-dominant) was conducted by Hornbuckle et al. (2010). In this study, 21 men and women (Mean $\pm$ SD: 22 $\pm$ 3 yrs; 24.5 $\pm$ 2.7 kg/m² BMI) wore AMs on both left and right wrists for 6-12 hours during a single day (8.3 $\pm$ 1.5 hrs). The authors concluded that there were no significant differences among PA outcome variables between wrist AMs. As a result, researchers now have the freedom to allow subjects to choose on which wrist they would prefer the AM to be placed. The option to choose which wrist to wear an AM becomes important when considering subject comfort and compliance. In adolescents however, no studies exists evaluating the impact of

dominant versus non-dominant or left versus right wrist AM placement. Similar to adults, the option to decide which wrist to wear AMs may augment subject comfort and subject compliance in adolescents. This, in turn, may put researchers in the best position to capture reliable estimates of free-living PA in adolescents.

CHAPTER THREE

THESIS MANUSCRIPT

Introduction

Improving techniques for the assessment of physical activity (PA) is one of the top research priorities for the exercise science field. Accurate assessments of PA are necessary to more objectively evaluate the health benefits associated with PA and the effectiveness of behavioral interventions designed to promote PA (Welk, Blair, Wood, Jones, and Thompson 2000). As in adults, habitual PA in children is important for health and well-being. Participation in daily PA becomes critically important in the prevention of hypokinetic diseases, such as obesity and type 2 diabetes mellitus, and has been associated with reduced mortality, morbidity, and better health, particularly with advancing age (Egerton and Brauer 2009; Paffenbarger et al. 1994). Therefore, valid and reliable estimates of daily PA for children and adolescents are required to develop appropriate PA promotional strategies.

Prior to the 2008 guidelines established by the U.S. Department of Health and Human Services (USDHSS), consensus PA recommendations for children and adolescents were lacking. With no standardized PA guidelines for children, the provisional recommendations across the U.S. were primarily subjective. Consequently, many children and adolescents may have been participating at a PA threshold far below the minimum requirements to maintain good health. Since 1980, the prevalence of child and adolescent obesity has tripled (Ogden et al. 2006) and has been associated with

metabolic health risks, chronic diseases, psychosocial problems and an increased risk of cardiovascular disease (CVD) in adulthood (Ebbeling, Pawlakk, and Ludwig 2002; Baker, Olsen, and Sorensen 2007). Moreover, trends in PA typically decline with increasing age, predominately during puberty and especially for females (Sherar et al. 2009; ACSM 2006). Thus, researchers need effective PA assessment strategies to study free-living PA patterns in children and adolescents.

The USDHHS guidelines (2008) were the first comprehensive PA guidelines ever issued by the Federal Government. The guidelines state that children and adolescents should accumulate at least 60 minutes or more of moderate to vigorous intensity aerobic activity daily as well as vigorous-intensity PA at least three days a week. Furthermore, children and adolescents should include both muscle and bone-strengthening PA on at least three days of the week as a part of their 60 or more minutes of PA.

Recent technological advances have allowed researchers to describe ambulatory PA using nonobtrusive motion sensors (Behrens and Dinger 2007). Accelerometry-based activity monitors (AMs), in particular, can provide information about the amount, frequency, and duration of PA (Plasqui and Westerterp 2007). These portable AMs are designed to detect and record bodily accelerations using one or multiple piezoelectric acceleration sensors. The resulting “raw” data from the activity monitors can be reported, via validated algorithms, as independent measures of time spent within different PA intensities, and/or converted into estimates of EE (Paul, Kramer, Moshfegh, Baer, and Rumpler 2007).

Generally worn at the wrist or hip, AMs have become exceedingly popular for measuring free-living PA in children. When positioned at the waistline (i.e., hip-worn monitors), the AM is most sensitive to vertical movements of the torso and thus describes measurements of whole-body PA. In adults, however, the hip-worn AM location has been associated with considerable compliance issues. The most acknowledged problems associated with hip-worn AMs are donning and doffing of the device at various times throughout the monitoring period. In addition, subjects not wearing the monitor on a given day, or forgetting to replace the monitor after a temporary removal are also commonly observed issues at the hip-worn location (Heil, Bennett, Bond, Webster, and Wolin 2009). In response to these compliance issues, alternative AM placement sites such as the wrist and ankle (Heil 2006; Heil et al. 2009) have been investigated.

Wearing compliance and AM placement are just a few practical issues to consider when assessing free-living PA of children. Where wrist AM placement may abate compliance issues commonly observed with hip-worn placement, the impact of AM placement on the wrists is still unclear. For example, should participants be allowed to choose which wrist to wear an AM? The convenience of user-preferred wrist AM placement in adolescents could attenuate noncompliance while consequently allowing for more reliable estimates of PA in children and adolescents under free-living conditions.

The only study known to investigate the impact wrist-worn AM placement was performed by Hornbuckle, Whitt-Glover and Heil (2010) in young adults (Mean $\pm$ SD: 22.3 $\pm$ 3 yrs). The authors concluded that there were no significant differences between measures from the left and right wrist-worn AMs. As a result, researchers can now allow

young adults the freedom to choose which wrist they prefer the monitor to be worn. To date, however, no studies have evaluated the impact of wrist-worn AM location (left or right wrist; dominant or non-dominant) on the measurement of free-living PA related variables in children or adolescents.

The outcome of wrist-worn AM placement (dominant versus non-dominant) on measurements of free-living PA in children and adolescents is a very important methodological issue to consider for researchers. Besides compliance problems, another issue to contemplate is comfort. The level of comfort, in turn, may directly influence the degree of subject compliance. When participants are asked to wear AMs on the wrist, the experience of wearing the device itself must not become a burden. Subject comfort becomes critically important when attempting to measure free-living PA patterns in children and adolescents using wrist-worn AMs where the highest level of conformity is desired. By allowing participants to actively choose which wrist, dominant or non-dominant, they would prefer the monitor to be placed may put the researcher in the best position to capture the most reliable representation of a child's or adolescent's free-living PA patterns.

The purpose of this study was to determine the influence of wearing AMs on the dominant versus non-dominant wrists on measurements of free-living PA in adolescents 12-17 years of age. The primary hypothesis was that summarized AM data expressed as total counts (counts/day), activity energy expenditure (AEE; kcals/day), and duration of time (Time; minutes/day) spent within intensity categories of light (L) and moderate-to-

vigorous (MV) PA, as well as for several minimum bout durations (1, 5, or 10 minutes), for both wrist-worn monitors (dominant and non-dominant) would be equal.

Methodology

Pre-Collection Phase

During the *Pre-Collection Phase*, informed consent documents and subject demographics were collected by the investigator. The study protocol was verbally explained to each participant during this phase. In addition, demographic information (e.g, age, body height, and mass) was used to initialize two AMs relative to each participant.

Subjects

Twenty adolescents from Bozeman, Montana, volunteered to participate in the current study. All subjects, along with a parent or legal guardian, read and signed an informed consent form (Appendix A), approved by the Montana State University Human Subjects Review Committee, describing the requirements and potential risks of participating in the study.

Study Protocol

Participation in this study required one initial visit to the Montana State University Movement Science Laboratory (MSL) in Bozeman, Montana. During the lab visit, subject demographics (e.g., age, body height and mass) along with contact information, were recorded and an informed consent was signed. During the visit,

subjects were given two activity monitors (AMs) to be worn (one for each wrist). Subjects were also given an activity diary to record daily bouts of PA for the duration of the study. Following the predetermined PA measuring period, subjects returned both AMs to the investigator at an off-campus location. The data was then downloaded to a personal computer using software provided by the manufacturer. Table 3.1 summarizes the study protocol.

Instrumentation

The Actical® AMs (Respironics Co., Inc., Bend, OR, USA) used in the current study were lightweight (17g), small ($2.8 \times 2.7 \times 1.0 \text{ cm}^3$), water resistant and were strapped bilaterally to the participants' wrists using plastic locking wristbands (Wristband Specialty Products, Deerfield Beach, FL, USA). According to the manufacturer, the Actical® is a omnidirectional AM because of its ability to measure acceleration in three dimensions (vertical, lateral, and horizontal) while being most sensitive within the vertical axes. The wrist-worn AMs were positioned with the Actical® logo pointing towards the hands of each participant. Forty Actical® AMs were used in the current study, all of which were calibrated and set to sample 15-s epochs prior to administering the devices to each subject. The resulting raw data, as measured by each Actical® AM, were expressed in count/min.

Collection Phase

The first laboratory visit took place on a weekday (Monday through Friday) where subjects were fitted with two Actical® AMs, one for each wrist. The wrist-worn

AMs were secured on the dorsal side of each wrist just proximal to the ulnar and radial styloid processes using locking plastic wristbands. Extra plastic wristbands were also provided for each subject in case a band size needed to be adjusted due to discomfort, or the original bands needed to be replaced during the monitoring period. Once strapped to each wrist, the AMs were to remain so for eight full days (including initial day) before removal on the ninth day. In addition, communication between the investigator and all subjects was maintained via phone, text, e-mail, and/or through parents for the duration of the study.

Table 3.1. Summarized Outline of Study Protocol

Day	Study Protocol
1	Meet with subjects, collect demographics, attached activity monitors, provide activity diary
2-8	Activity monitor wear time (measuring period)
9	Collect monitors and activity diary

Post Collection Phase

Following the allocated PA measuring period of seven full days, subjects met the investigator a second time at an off-campus location. During this meeting, both AMs were returned to the investigator and the data from both AMs were downloaded to a personal computer using software provided by the Actical ® manufacturer (Actical V2.0, Respironics Co., Inc., Bend, OR, USA).

Quality and Quantity Control Checks

The purpose of the Quality and Quantity Control Checks (QQCC) were to recognize raw data points not accurately representing subjects' free-living PA (Heil et al.

In press). Quality control checks or “data cleansing” was performed on the raw data recorded by each AM to check for spuriously high and/or low values per Actical® software. This method employs a combination of quantitative and qualitative assessment techniques. *Quantitative* methods visually evaluate raw data points that exceed predetermined thresholds whereas *qualitative* methods often assess time-based plots visually for any suspected anomalies. Quality checks also visually screen for compliance issues or monitor malfunctions that may have occurred during the AM wear time

Quantity control checks were performed to identify periods on non-wear and to ensure behavioral reliability requirements were satisfied (Heil et al. In press). Non-wear times or monitor malfunctions generated missing or incomplete data all of which were systematically handled and described in the results section. As a prerequisite to data processing, each subject must have worn the AM for a full seven days (24 hrs/day) during the monitoring period.

Data Transformations

The raw AM data for all subjects were imported into a custom Visual Basic (Version 6.0) program for conversion to minute-by-minute activity energy expenditure (AEE; kcal/kg/min). Activity energy expenditure was calculated from raw AM data in counts/min, using previously validated single (1R) and double regression (2R) modeling algorithms for wrist location (Table 3.2) developed under lab-based conditions (Heil 2006). Table 3.2 summarizes the cut points and prediction equations that constitute these algorithms.

Table 3.2. Summary of single (1R) and double (2R) regression algorithms for converting raw activity monitor output to activity energy expenditure (AEE) in children 8-17 years of age at the wrist location (Heil 2006).

Model	CP1	CP2	Constant AEE: when $50 < AC < CP1$	Predicted AEE: $CP1 \leq AC < CP2$	Predicted AEE: $AC \geq CP1$	Predicted AEE: $AC \geq CP2$
1R	900	N/A	0.01130	N/A	$AEE = 0.02299 + (1.902E-5) \times AC$	N/A
2R	900	2000	0.01130	$AEE = 0.01149 + (3.236E-5) \times AC$	N/A	$AEE = 0.03115 + (1.581E-5) \times AC$

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

Following the transformation of raw AM output into AEE, the Visual Basic program searched each AEE file for predetermined PA bouts lasting a minimum of 1, 5, and 10 minutes in duration and that fell into the intensity categories of light (L) and moderate-to-vigorous (MV) PA. The intensity categories of L and MV were defined by previously established AEE cut points. Intensity of PA was considered light if AEE was below <0.05 kcal/kg/min, moderate if AEE was between 0.05 and 0.09 kcal/kg/min, and vigorous if AEE was equal to or above 0.10 kcal/kg/min (Puyau, Adolph, Vohra, and Butte 2002). The subsequent outcome of this search performed by the program, resulted in a corresponding duration (Time; mins) spent within a specified intensity, summation of AEE, and total counts for each bout duration and monitoring day.

Statistical Analysis

The resulting dependent variables (Counts, AEE, Time) for each bout duration (1, 5, and 10 minutes) within L and MV intensity category and from each AM (dominant

versus non-dominant) were compared using a two-factor (AM placement x Bout Duration) multivariate repeated measures analysis of variance (RMANOVA) ($\alpha=0.05$). Scheffe's post-hoc analyses were performed at the 0.01 alpha level for all pairwise comparisons when indicated by the ANOVA analysis. The same analyses (RMANOVA and Scheffe's post-hoc) were also used to analyze the same data set to compare left versus right wrist-worn AM output. All data were analyzed using Statistix V9 (Analytical Software, Tallahassee, FL, USA). Pearson's correlation was also performed to analyze the relationship between dependent variables for all bout durations within L and MV intensity categories between AMs (D versus ND and between LW versus RW) ($\alpha = 0.05$). Correlations were analyzed using Statistica (StatSoft, Tulsa, OK, USA). The above analyses were performed on data processed by both the 1R and the 2R calibration algorithms.

Results

A total of 25 adolescent subjects participated in the study. However, at the end only 20 adolescents had data files that were successfully retrievable and processed. During the QQCC in the *Post-Collection Phase*, five subjects had raw AM data with spurious biosignal values due to AM malfunctions on one or both of the wrist-worn AMs (Figure 3.1). Demographics for the 20 adolescents whose monitors contained retrievable data are described in Table 3.3.

Single Regression Calibration Algorithm:

There were no significant differences between dependent variables (Counts, AEE, Time) within light (L) (CNT_L , AEE_L , T_L) or moderate-to-vigorous (MV) (CNT_{MV} , AEE_{MV} , T_{MV}) for any bout duration (1, 5, or 10 minutes) between dominant (D) and non-dominant (ND) wrist-worn activity monitors (AMs) using the 1R algorithm. Similarly, there were no significant differences between dependent variables for any bout duration within L or MV intensity between left (LW) and right (RW) wrist-worn AMs using the 1R algorithm.

Double Regression Calibration Algorithm:

Similar to the 1R results, when the data were processed using the 2R algorithm, there were no significant differences between mean counts for any bout duration between D and ND, or between LW and RW AMs within L (Table 3.5) or MV intensities (Table 3.6). Since the RMANOVA results were the same for data processed by both the 1R and 2R calibration algorithms, the remaining results will focus exclusively on the 2R output.

Additionally, no differences in mean AEE values between AMs (D versus ND or LW versus RW) for any bout duration within L (Table 3.7) or MV (Table 3.8) intensities were observed. Likewise, no significant differences existed between mean time for any bout duration within L (Table 3.9) or MV (Table 3.10) intensities between AMs (D versus ND or LW versus RW). There were significant differences, however, *between* bouts (1, 5, and 10 minutes) for all dependent variables CNT_L , AEE_L , T_L and CNT_{MV} , AEE_{MV} , and T_{MV} when assessed by D versus ND and LW versus RW AMs for both 1R and 2R, as indicated by Scheffe's All-Pairwise Comparisons post-hoc analyses.

Figure 3.1. Systematic Diagram of Pre-Collection, Collection, and Post-Collection Phases.

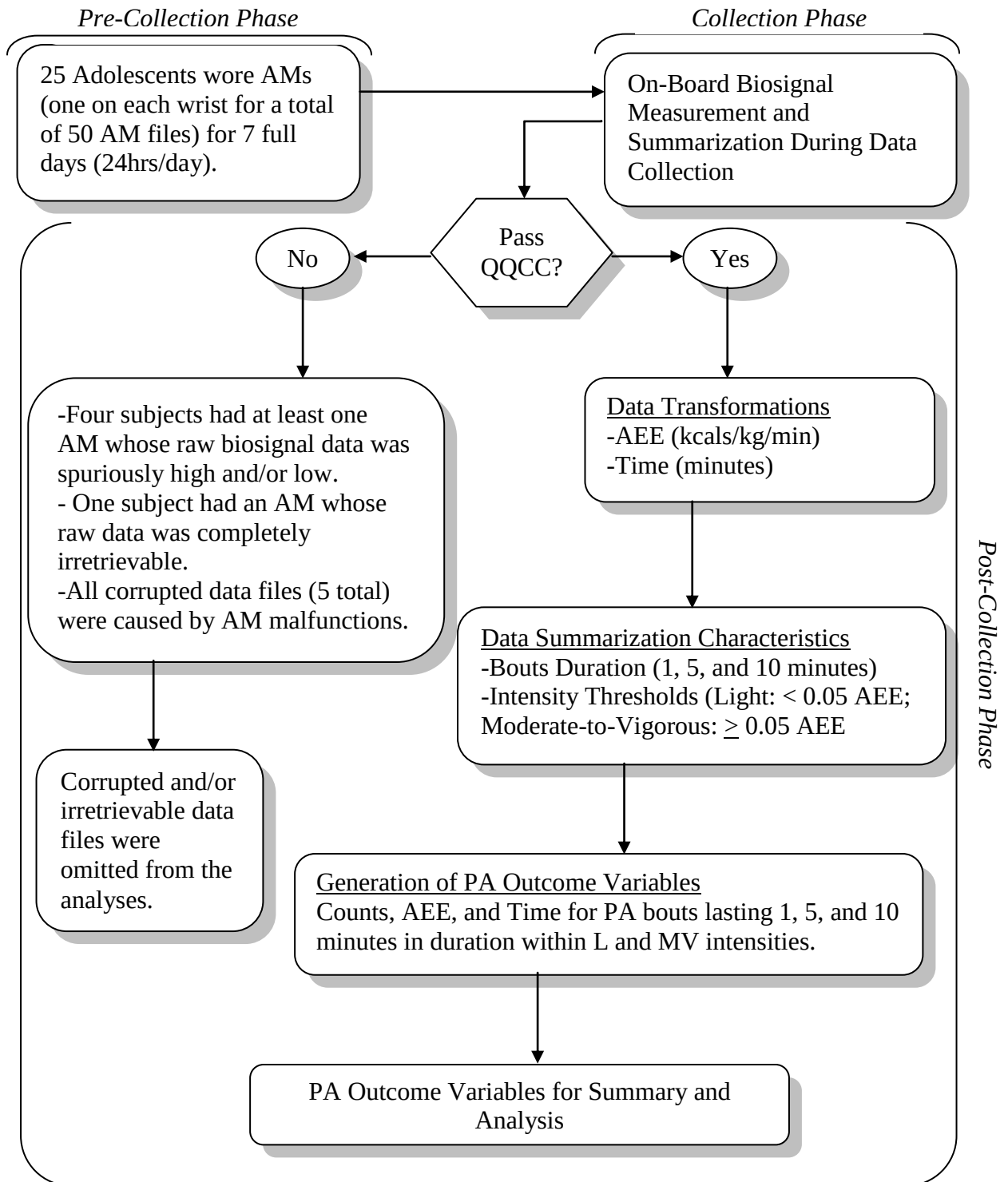


Table 3.3. Demographic characteristics of all participants.

Subject	Gender	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m ²)	Dominant Hand
1	M	14	167.0	61.5	22.1	Right
2	M	14	149.2	48.5	21.8	Left
3	F	13	165.4	62.4	22.8	Right
4	M	13	152.5	44.2	19.0	Right
5	F	17	161.0	63.5	24.5	Right
6	F	13	156.0	46.4	19.1	Right
7	M	16	176.0	63.9	20.6	Right
8	M	17	163.5	64.9	24.3	Right
9	F	13	161.0	64.9	25.0	Right
10	F	12	155.0	51.6	21.5	Left
11	M	16	184.2	73.0	21.5	Right
12	F	16	165.0	64.6	23.7	Right
13	F	14	173.0	68.5	22.7	Right
14	F	14	165.5	60.5	22.1	Right
15	F	12	151.5	40.5	17.6	Right
16	F	14	168.5	56.5	19.9	Right
17	M	12	146.0	38.0	17.8	Right
18	M	12	145.5	37.5	17.7	Left
19	F	16	149.0	38.0	17.1	Right
20	F	13	153.0	56.5	21.1	Right
Mean		14.1	160.4	55.2	21.1	
SD		1.7	10.5	11.2	2.4	
Range		12-17	145.5-184.2	37.5-73.0	17.1-25.0	

Note: Hand dominance was defined as subjects' preferred hand for writing.

Table 3.4. Subject demographics by gender (Mean±SD).

	n	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m ²)
Boys	8	14.3±1.9	160.5±14.5	53.9±13.6	20.6±2.3
Girls	12	13.9±1.6	160.3±7.4	56.1±9.9	21.4±2.6

Table 3.5. Summarized data for activity counts (AC) in light physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Light Intensity				
Bout	Dominant Hand AC	Non-Dominant Hand AC	Left Wrist AC	Right Wrist AC
1-minute	226937(6988)	226887(6844)	226637(6704)	227187(7122)
5-minute	193915(7134)	196209(7415)	196538(7239)	193587(7306)
10-minute	145014(7127)	150227(8024)	150495(7711)	144746(7454)

Note: AC = Activity counts (counts/day); 2R = Double Regression; SE = standard error

Table 3.6. Summarized data for activity counts (AC) in moderate-to-vigorous physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Moderate-to-Vigorous Intensity				
Bout	Dominant Hand AC	Non-Dominant Hand AC	Left Wrist AC	Right Wrist AC
1-minute	329137(33677)	309616(36250)	303133(34491)	335620(35226)
5-minute	227997(27031)	212933(28259)	208013(27015)	232917(28091)
10-minute	128297(18485)	117895(18344)	115438(18107)	130754(18629)

Note: AC = Activity counts (counts/day); 2R = Double Regression; SE = standard error

Table 3.7. Summarized data for activity energy expenditure (AEE) in light physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Light Intensity				
Bout	Dominant Hand AEE	Non-Dominant Hand AEE	Left Wrist AEE	Right Wrist AEE
1-minute	486.2(24.2)	490.2(24.5)	490.5(24.1)	485.9(24.5)
5-minute	390.3(19.1)	399.4(20.4)	400.3(19.8)	389.4(19.7)
10-minute	281.5(14.6)	297.3(17.3)	297.8(16.6)	280.9(15.3)

Note: AEE = Activity Energy Expenditure (kcal/day); 2R = Double Regression; SE = standard error

Table 3.8. Summarized data for activity energy expenditure (AEE) in moderate-to-vigorous physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Moderate-to-Vigorous Intensity				
Bout	Dominant Hand AEE	Non-Dominant Hand AEE	Left Wrist AEE	Right Wrist AEE
1-minute	563.1(52.8)	515.6(52.4)	506.7(50.6)	572.0(53.9)
5-minute	380.2(40.2)	342.6(39.8)	335.6(38.6)	387.2(40.9)
10-minute	209.9(25.9)	182.9(24.8)	180.2(25.1)	212.7(25.5)

Note: AEE = Activity Energy Expenditure (kcal/day); 2R = Double Regression; SE = standard error

Table 3.9. Summarized data for duration of time (T) in light physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Light Intensity				
Bout	Dominant Hand Duration	Non-Dominant Hand Duration	Left Wrist Duration	Right Wrist Duration
1-minute	614.4(13.9)	626.5(15.6)	627.9(15.6)	612.9(13.8)
5-minute	503.4(15.9)	519.6(18.0)	521.3(17.8)	501.7(16.0)
10-minute	374.6(17.8)	396.1(20.1)	396.8(19.7)	373.9(18.3)

Note: Time (mins/day); 2R = Double Regression; SE = standard error

Table 3.10. Summarized data for duration of time (T) in moderate-to-vigorous physical activity intensity using the 2R algorithm (Mean $\pm$ SE).

Moderate-to-Vigorous Intensity				
Bout	Dominant Hand Duration	Non-Dominant Hand Duration	Left Wrist Duration	Right Wrist Duration
1-minute	144.9(11.9)	132.0(12.6)	129.8(12.1)	147.2(12.3)
5-minute	95.7(9.9)	85.3(10.3)	83.6(10.0)	97.4(10.1)
10-minute	52.2(6.6)	44.9(6.6)	44.5(6.9)	52.7(6.3)

Note: Time (mins/day); 2R = Double Regression; SE = standard error

There were very high correlations ($r = > 0.85$, $p\text{-value} < 0.0001$) between all output variables (CNT, AEE, T) for all bout durations (1, 5, and 10 minutes) within L and MVPA intensity categories between AMs (D versus ND and LW versus RW). Figures 3.2 and 3.3, for example, show the significant relationships for T_{MV} for all bout durations between D and ND (Figure 3.2) and between LW and RW (Figure 3.3) AMs. Likewise, high correlations were observed for CNT, AEE, and T for all bout durations within L and MVPA intensity categories between AMs (D versus ND and LW versus RW). The correlation for these latter variables are not reported due to their similarity with those already reported.

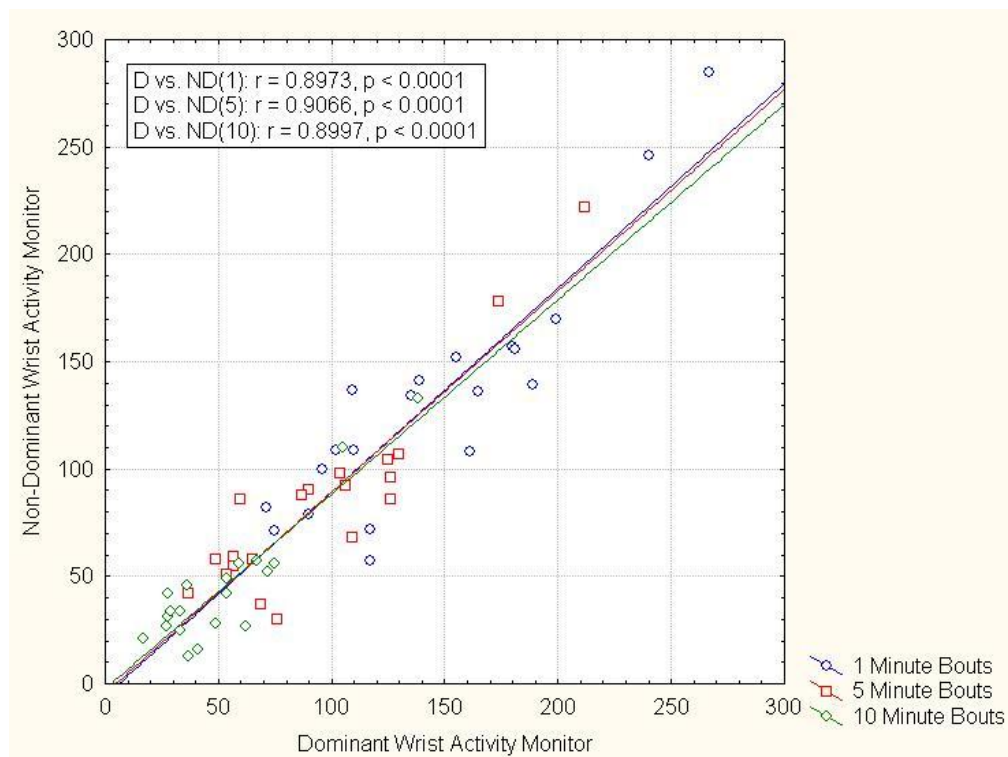


Figure 3.2. Relationship between duration of time spent in moderate-to-vigorous physical activity intensity for all bout durations between dominant (D) and non-dominant (ND) activity monitors. Correlations and plotted lines are the result of best-fit linear regression for D versus ND within each bout duration.

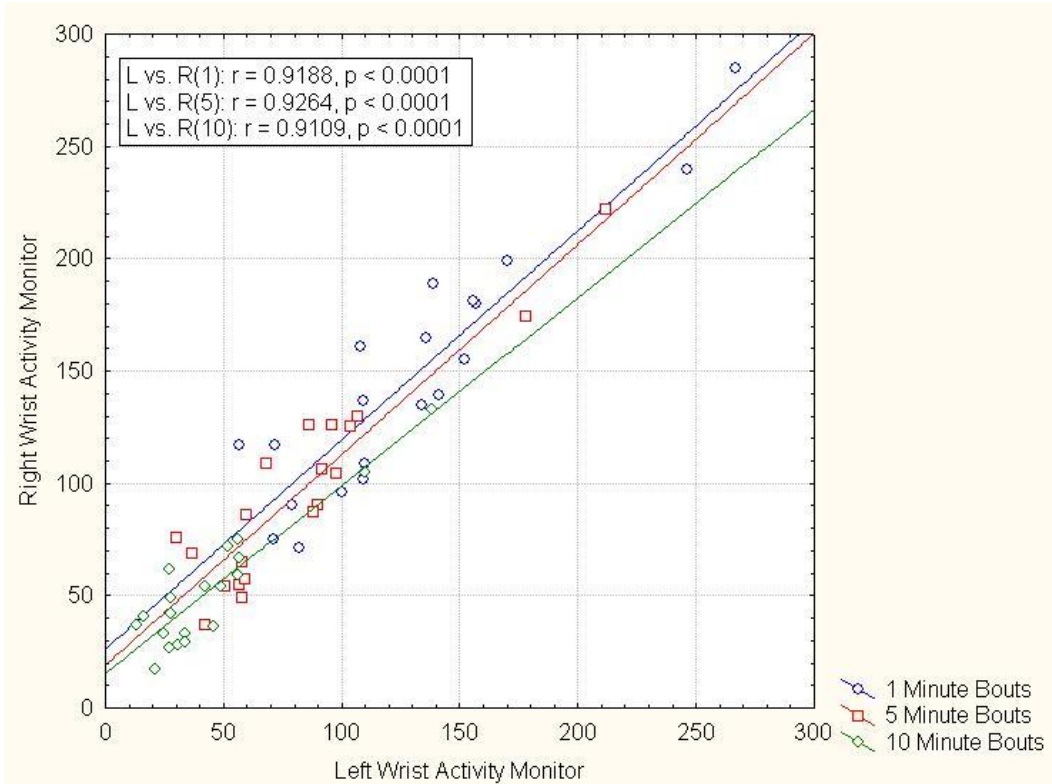


Figure 3.3. Relationship between duration of time spent in moderate-to-vigorous physical activity intensity for all bout durations between left (L) and right (R) wrist activity monitors. Correlations and plotted lines are the result of best-fit linear regression for LW versus RW within each bout duration.

Subgroup Analyses

In response to the statistical similarities observed for outcome variables between AMs (D versus ND and between LW versus RW), a subgroup analysis compared outcome variables between D and ND and between LW and RW AMs within gender. Splitting the entire sample by gender, the same analyses reported for the full sample were repeated within the subsample of boys ($n=8$) and girls ($n=12$) separately. An overall trend was for D AM values to always be non-significantly higher than ND values for the MV intensity (Table 3.11). In contrast, ND tended to be non-significantly higher than D at the

L intensity. Likewise, there was a tendency for RW values to be insignificantly higher than LW values for the MV intensity (Table 3.12). Although not statistically meaningful, LW values tended higher than RW values at L intensity.

There were consistent trends for boys to be more physically active than girls. Table 3.11 shows that T_{MV} from the D and ND wrist monitors for boys were consistently higher than girls, respectively, for each bout duration. Similarly, RW T_{MV} mean values for boys were consistently higher than RW T_{MV} for girls (Table 3.12).

A second subgroup analysis was performed to evaluate differences between the 10 lowest active and 10 highest active adolescents ($n=20$), between both AMs (D versus ND; LW versus RW). The 10 lowest and 10 highest active subjects were identified by the duration of time spent within MVPA intensity. For example, the 10 subjects with the lowest T_{MV} values (lowest active) for the D wrist were compared with the 10 lowest active adolescents for the ND wrist. Likewise, the 10 subjects with the highest T_{MV} (highest active) for the D AM were contrasted with the 10 highest active adolescents for the ND AM. This same comparison analysis was also performed on LW versus RW outcome variables. This additional subanalysis resulted in no significant differences within any of the PA subgroups tested.

Table 3.11. Duration of time (T) spent within moderate-to-vigorous intensity for all bouts from dominant and non-dominant activity monitors separated by gender (Mean $\pm$ SE).

Bout	Gender	Moderate-to-Vigorous Intensity	
		Dominant Wrist	Non-dominant Wrist
1-Minute	Boys	174.6 $\pm$ 22.2	164.4 $\pm$ 24.6
	Girls	125.1 $\pm$ 10.5	110.4 $\pm$ 9.8
5-Minute	Boys	117.6 $\pm$ 20.1	109.6 $\pm$ 21.5
	Girls	81.0 $\pm$ 8.0	69.0 $\pm$ 7.0
10-Minute	Boys	65.5 $\pm$ 14.1	59.1 $\pm$ 14.5
	Girls	43.3 $\pm$ 4.6	35.5 $\pm$ 4.1

Note: Boys (n=8); Girls (n=12); T = minutes/day

Table. 3.12. Duration of Time (T) spent within moderate-to-vigorous intensity for all bouts from left and right wrist activity monitors separated by gender (Mean $\pm$ SE).

Bout	Gender	Moderate-to-Vigorous Intensity	
		Left Wrist	Right Wrist
1-Minute	Boys	162.3 $\pm$ 23.1	176.8 $\pm$ 23.7
	Girls	108.1 $\pm$ 9.5	127.4 $\pm$ 10.4
5-Minute	Boys	108.6 $\pm$ 20.5	118.6 $\pm$ 21.1
	Girls	66.8 $\pm$ 6.9	83.2 $\pm$ 7.8
10-Minute	Boys	59.8 $\pm$ 14.5	64.9 $\pm$ 13.7
	Girls	34.3 $\pm$ 4.1	44.5 $\pm$ 4.4

Note: Boys (n=8); Girls (n=12); T = minutes/day

Discussion

Although the Actical® AM has been utilized as a device for measuring PA in adolescents in previous research, this is the first study, to the authors knowledge, to study the placement of the wrist-worn Actical® AM in this population. The results of this study confirm that when using the Actical® AM to assess free-living PA in adolescents at the wrist, outcome variables are statistically similar regardless of hand dominance (D versus ND) or data calibration algorithm. These findings are in agreement with an earlier study conducted by Hornbuckle, Whitt-Glover, and Heil (2010). Although the latter study was performed on a group of young adults (Mean±SD: 22.3±3 yrs), both studies provide evidence that choice of wrist placement (D versus ND, or LW versus RW) is relatively unimportant when measuring PA under free-living conditions.

There were common trends for mean values of CNT, AEE, and T to steadily decline with increases in intensity and bout duration. In other words, there was an inverse relationship between mean output variable values and increasing intensity and duration. This inverse relationship can be observed in Figures 3.2 and 3.3 as well as Tables 3.5-3.10 and was true for all dependent variable comparisons for all bout durations between AMs (D versus ND, and between LW versus RW). This finding is not surprising given the prevalence of child and adolescent obesity and sedentary behavior (Ogden 2006; Sisson, Broyles, Baker, and Katzmarzyk 2010).

In addition to the current study, there are only a handful of studies that have evaluated alternative contralateral AM placement sites. Nichols et al. (1999) performed a study on 60 young adults (Mean±SD: 23.4±2.9 yrs) to evaluate the validity and reliability

of the Tritrac RD3 AM when worn on the right and left hips. They conclusively found that there were no significant differences in AC output values between the left and right hip worn AMs ($p > 0.05$) and found intraclass reliability coefficients for the left and right AM to range from 0.87 to 0.92. Further, Trost and colleagues (1998) conducted a study to determine the interinstrument reliability of an accelerometer (CSA) when positioned on the left and right hips in a group of children 10-14 years of age. Each subject performed three 5-minute treadmill bouts at 3, 4, and 6 mph, respectively. The authors found an intraclass correlation coefficient (ICC) value of 0.87 for the two CSA monitors. Taken together, these reliability studies (Nichols et al.1999; Trost et al.1998) suggest there is little variation between contralateral hip-worn AMs. According to Welk et al. (2005), it makes little difference where the AM is placed (left or right hip) but the need for a standardized AM wear protocol would suggest that one side be used consistently. The current study adds to a body of evidence that suggests there is little to no variation between contralateral AM wear locations (e.g., left hip, right hip or left wrist, right wrist).

In contrast, the variability between monitors can fluctuate between different wearable locations. For example, Heil et al. (2009) evaluated the influence of AM wear location on PA outcome variables under free-living conditions. Participants (Mean $\pm$ SD: 26 $\pm$ 6 yrs) wore AMs at three locations (wrist, hip, and ankle) for a single day. The wrist-worn AM was attached to the non-dominant wrist and another AM was attached to the ipsilateral ankle. The hip-worn AM was attached to the waistline and posteriorly to the right iliac crest. Mean values at the ankle were significantly higher when compared to mean output values measured at the hip and wrist-worn AM locations, whereas mean hip

and wrist-worn AM outcome variables were statistically similar. Since the hip-worn location possess a hypothetical advantage (closest to body's center of mass), the ND wrist-worn location may be the better alternative when compared to the ankle for measuring free-living PA in young adults. The practical significance of the ND wrist location being more similar to values measured at the hip, in conjunction with the Hornbuckle et al. (2010) study, suggest that the ND wrist is not only a valid location for measuring free-living PA but that either wrist (D or ND) is a viable AM wear location in young adults. It is theoretically plausible that this inference may be extended to adolescents, however, further evidence in adolescent-based research needed to substantiate this conjecture.

The subgroup analyses were performed in response to a lack of significant differences between outcome variables for any bout duration within L and MVPA intensity categories between AMs (D versus ND and between LW versus RW). There were no significant differences observed for any variable between monitors (D versus ND or between LW versus RW) within gender. Further, there was no evidence for any statistical differences among the 10 lowest active adolescents when comparing D versus ND or between LW versus RW. Similarly, no significant differences existed among the 10 highest active adolescents between monitors (D versus ND or between LW versus RW). When compared to the 2008 USDHHS guidelines, both boys and girls in the current study, fall short of meeting the federal recommendations of accumulating 60 of MVPA daily. Mean values for duration of time spent within a MVPA intensity were reported because this variable adequately provides information about intensity and

duration of activity and as a result, can be compared directly to PA guidelines.

Overall, males tended to have higher summarized output values for CNT, AEE, and T spent within L and MVPA. This finding corroborates similar findings in a review by Hoos, Gerver, Kester and Westerterp (2003). The authors concluded that children and adolescent boys generally exhibited higher AEE values than girls. Further, the researchers hypothesized that the observed differences in AEE were likely due to the difference in body composition between genders. In addition, this notion of adolescent males being more physically active than females is supported in a study by Casperson, Pereira, and Curran (2000). The authors concluded that male adolescents were typically more physically active than their female counterparts, particularly when the intensity of the activity increased. For the current study, the trend of males being more physically active was evident in the larger AM outcome variables for CNT, AEE, and T spent within L and MVPA.

Between Bout Differences

Although there were no significant differences for any dependent variable (CNT, AEE, T) for any bout duration (1, 5, and 10 minutes) within L and MVPA between AMs (D versus ND and LW versus RW), there were significant differences for all dependent variables (CNT_L, AEE_L, T_L, and CNT_{MV}, AEE_{MV}, and T_{MV}) between bout durations. For example, mean counts accrued within L intensity for 1-minute bouts from the D and ND AMs were significantly higher than mean counts accumulated within 5 and 10 minute bouts. Likewise, mean counts from 5-minute bouts were significantly different from 1 and 10 minute bouts. A bout of PA had to last at least 10 minutes or greater to be counted

as a 10 minute bout. When compared to 1 or 5-minute bout durations, the definition of a 10 minute bout is simply a more rigorous definition and is the reason why outcome values were the highest for 1 minute bout durations and lowest for 10-minute bouts.

Omitted Data

Following the Quality and Quantity Control Checks (QQCC) in the *Post-Collection Phase*, five data files were considered corrupted and/or irretrievable data due to spurious biosignal values or electronic communication errors during the *Collection Phase*. Prior to attaching the AMs to the participants, all AM battery lives were checked and, if needed, replaced. Upon recognizing the erroneous data from the five data file Actograms, the AMs to which those files belonged were evaluated for potential damage. It was concluded that water had penetrated each AM, specifically around the plate that secures the battery in place. This was most likely due to insufficient tightening of the plate to the AM during battering replacement.

Compliance

In 2006, the wrist wearing location was determined to be a suitable alternative to the hip for placing AMs when assessing PA in adolescents (Heil 2006). The wrist-worn location was further validated by Heil et al. (2009) to be a valid placement site when measure free-living PA in adults. The wrist-worn site was initially investigated in response to wide spread compliance issues associated with the hip-worn location when using these portable measuring devices. For the current study, there were no notable compliance issues to report. The only documented reason for removing a monitor was

due to occasional swelling of the wrists for two participants. As a result, each participant cut off the initial band, only to replace it immediately with an alternative band provided by the investigator.

Conclusions

The results of this study represent the first research to examine the influence of wrist-worn AMs in adolescents under free-living conditions. These results suggest that there were no significant differences between output variables (CNT, AEE, and T) within L and MVPA intensities between wrist-worn AMs (D versus ND, or between LW versus RW) or data calibration algorithm. These findings are important for researchers using the Actical® AM to objectively assess free-living PA patterns in adolescents. As in adults, researchers now have the freedom to allow subjects the option to choose which wrist they would prefer the AM to be placed. In addition, there was a lack of significant differences between data analyzed by the 1R and 2R algorithms. Selection of a processing algorithm is a task solely for the researcher and should be upon the question(s) of interest, population, AM type, and wear location.

CHAPTER 4

CONCLUSIONS

There were no statistical differences between outcome variables for any bout duration (1, 5, or 10 minutes) within L and MV intensity categories between AMs (D versus ND; LW versus RW) or model (1R versus 2R). According to these results, researchers now have the option to allow adolescent participants the opportunity to choose which wrist they would prefer the AM to be placed when using the Actical[®] AM. Further, there was a lack of significant differences between data analyzed by the 1R and 2R algorithms. The selection of the data processing algorithm is a responsibility exclusive to the researcher and should be based upon the question(s) of interest, population, AM type, and wear location.

Outcome variables from the D and RW AM correlated highly with counterpart variables from the ND and LW AM, respectively, for all bout durations (1, 5, and 10) within L and MVPA intensity categories. Further, there was a significant trend for adolescents to spend a majority of their time performing L PA that lasted 1 minute in duration when compared to 10 minute PA bouts in MVPA intensity.

Dominant and RW AMs were non-significantly higher than ND and LW, respectively, within MVPA intensity. In contrast, ND and LW AMs were non-significantly higher than D and RW within L intensity PA. Identical results were found when analyzed within gender. This relationship may be partially explained by the low number of adolescents who were left handed, which could be why these statistical comparisons (D and RW and between ND and LW) were very similar. Seventeen of the

20 participants considered their right hand to be their dominant hand, whereas three considered their left hand to be their dominant hand.

As a second PA sub-group analysis, subjects were split into the 10 lowest and 10 highest active for each AM (D and ND and for LW and RW). When the 10 lowest active from the D were compared with the 10 lowest from the ND, no significant differences existed. Likewise, comparisons among the 10 highest active between D and ND wrists were not statistically meaningful. Further, this non-significant relationship was true the same comparisons between LW and RW AMs.

One limitation to the current study was the lack of adolescents who considered themselves to be left handed. Future studies may want to consider equal numbers of those who claim right hand dominance and left hand dominance so that no group is underrepresented. To further elucidate the influence of AM placement on PA outcome variables, future studies should evaluate the impact of other contralateral placement locations such as the hips and ankles.

REFERENCES

- American College of Sports Medicine (ACSM) (2006) Exercise testing and prescription for children and elderly people. In: M. H. Whaley (ed.) Guidelines for Exercise Testing and Prescription, 7th edn, Baltimore, Maryland, pp 241-242
- Bailey R, Olson J, Pepper S, Porszasz J, Barstow T, and Cooper D (1995) The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc* 27:1033-1041
- Baker J, Olsen L, and Sorensen T (2007) Childhood body-mass index and the risk of coronary heart disease in adulthood. *N Engl J of Med* 357:2329-2337
- Baquet G, Stratton G, Van Praagh, and Berthoin S (2007) Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: a methodological issue *Prev Med* 44:143-147
- Barkanowski T, Smith M, Thompson W, Baranowski J, Hebert D, and De Moor C (1999) Intra-individual variability and reliability in a 7-day exercise record. *Med Sci Sports Exerc* 3:1619-1622
- Behrens T, and Dinger M (2007) Motion sensor reactivity in physically active young adults. *Res Q Exerc and Sport* 78:1-8
- Casperson C, Pereira M, and Curran K (2000) Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc* 32:1601-1609
- Casperson C, Powell K, and Christenson G (1985) Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Pub Health Rep* 100:126-131
- Chen K, and Bassett D Jr, (2005) The technology of accelerometry-based activity monitors: current and future. *Med Sci Sports Exerc* 37:S490-S500
- Cobayashi F, Oliveira F, Escrivão M, Silveira D, Iaddei J (2010) Obesity and cardiovascular risk factors in adolescents attending public schools. *Arq Bras Cardiol* 95: 200-206
- Deshmukh-Taskar P, Nicklas T, Morales M, Yang S, Zakeri I, Berenson G (2006) Tracking of overweight status from childhood to young adulthood: the Bogalusa Heart Study. *Euro J Clinical Nutr* 60:48-57

- Ebbeling C, Pawlak D, Ludwig D (2002) Childhood obesity: public-health crisis, common sense cure. *Lancet* 360:473-482
- Egerton T, and Brauer G (2009) Temporal Characteristics of habitual physical activity periods among older adults. *J Phys Act Health* 6:644-650
- Ekelund U, Sjöström M, Yngve A, Poortvliet E, Nilsson A, Fromberg K, Wedderkopp N, and Westerterp K (2001) Physical activity assessed by activity monitor and doubly labeled water in children. *Med Sci Sports Exerc* 33:275-281
- Eston R, Rowlands A, and Ingledew D (1998) Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. *J Appl Physiol* 84:362-371
- Freedson P, Pober D, and Janz K (2005) Calibration of accelerometer output for children. *Med Sci Sports Exerc* 37:S523-S530
- Hedley A, Ogden C, Johnson C, Carroll M, Curtin L, and Flegal K (2004) Prevalence of overweight and obesity among US children, adolescents, and adults, 1992-2002. *J Amer Med Assoc* 291:2847-2850
- Heil D (2006) Predicting activity energy expenditure using the Actical activity monitor. *Res Q Exerc Sport* 77:64-80
- Heil D, Bennett G, Bond K, Webster M, and Woling K (2009) Influence of activity monitor location and bout duration on free-living physical activity. *Res Q Exerc Sport* 80:424-433
- Heil D, Brage S, and Rothney M (In press) Modeling outcomes from wearable monitors. *Med Sci Sports Exerc*
- Hoob M, Gerver W, Kester A, and Westerterp K (2003) Physical activity levels in children and adolescents. *Inter J Obes* 27:605-609
- Hornbuckle L, Whitt-Glover M, and Heil D (2010) A comparison of physical activity variables from bilateral wrist-worn accelerometers. *Med Sci Sports Exerc* Abstract: May, 2010
- Kollle E, Steene-Johannessen J, Anderson L, and Anderson S (2010) Objectively assessed physical activity and aerobic fitness in a population-based sample of Norwegian 9- and 15-year-olds. *Scand J Med Sci Sports* 20:e41-e47

- Laporte, R.E., Montoye, H.J., and Caspersen, C.J. (1985). Assessment of physical activity in epidemiologic research: problems and prospects. *Public Health Reports*, 100, 131-145
- Masse L, Fuemmeler B, Anderson C, Matthews C, Trost S, Catellier D, and Treuth M (2005) Accelerometer data reduction: a comparison of four reduction algorithms on selected outcome variables. *Med Sci Sports Exerc* 37:S544-S554
- Matthews C, Ainsworth B, Thompson R, and Bassett D Jr (2002) Sources of variance in daily physical activity levels as monitored by an accelerometer. *Med Sci Sports Exerc* 34:1376-1381
- Matthews C, Hebert J, Freedson P, Stanek E, Merriam P, Ebbeling C, and Ockene I (2001) Sources of variance in daily physical activity levels in the seasonal variation of blood cholesterol study. *Amer J Epidemiol* 153:987-995
- McMurray R, Baggett C, Harrell J, Pennell M, and Bangdiwala S (2004) Feasibility of the Tritrac R3D accelerometer to estimate energy expenditure in youth. *Ped Exerc Sci* 16:219-230
- Melanson E, Knoll J, Bell M, Donahoo W, Hill J, Nysse L, Lanningham-Foster L, Peters J, and Levine J (2004) Commercially available pedometers: considerations for accurate step counting. *Prev Med* 39:361-368
- Ogden C, Carroll M, Curtin L, McDowell M, Tabak C, and Flegal K (2006) Prevalence of overweight and obesity in the United States, 1999-2004. *J Amer Med Assoc* 295:1549-1555
- Paffenbarger Jr, R, Kampert J, Lee I-Min, Hyde R, Leung R, and Wing A (1994) Changes in physical activity and other lifeway patterns influencing longevity. *Med Sci Sports Exerc*, 26:857-865
- Paul D, Kramer M, Moshfegh A, Baer D, and Rumpler W (2007) Comparison of two different physical activity monitors. *BMC Med Res Methodology* 7:26. doi:10.1186/1471-2288-7-26
- Plasqui G, and Westerterp K (2007) Physical activity assessment with accelerometer: an evaluation against doubly labeled water. *Obesity* 15:2371-2379
- Puyau M, Adolph A, Vohra F, and Butte N (2002) Validation and calibration of physical activity monitors in children. *Obes Res* 10:150-157
- Puyau M, Adolph A, Vohra F, Zakeri I, and Butte N (2004) Prediction of activity energy expenditure using accelerometers in children. *Med Sci Sport Exerc* 36:1625-1631

- Rikli R (2000) Reliability, validity, and methodological issues in assessing physical activity in older adults. *Res Q Exerc Sport* 71:S89-S96
- Rowlands A (2007) Accelerometer assessment of physical activity in children: an update. *Ped Exerc Sci* 19:252-266
- Rowlands A, Stone M, and Eston R (2007) Influence of speed and step frequency during walking and running on motion sensor output. *Med Sci Sports Exerc* 39:716-727
- Rowlands A, Thomas P, Eston R, and Topping R (2004) Validation of the RT3 triaxial accelerometer for the assessment of physical activity. *Med Sci Sports Exerc* 36:518-524
- Sallis J, and Saelens B (2000) Assessment of physical activity by self-report. Status, limitations, and future directions. *Res Q Exerc Sport* 71:S1-S14
- Schneider P, Crouter S, and Bassett D (2004) Pedometer measures of free-living physical activity: comparison of 13 models. *Med Sci Sports Exerc* 36:331-335
- Sherar L, Gyurcsik N, Humbert M, Dyck R, Fowler-Kerry F, and Baxter-Jones A (2009) Activity and barriers in girls (8-16yr) based on grade and maturity status. *Med Sci Sports Exerc* 41:87-95
- Sinard J, and Slater M (2009) Compliance with wearing physical activity accelerometers in high school students. *J Phys Act Health* 6:S148-S155
- Sisson S, Broyles S, Baker B, and Katzmarzyk P (2010) Screen time, physical activity, and overweight in U.S. youth: national survey of children's health 2003. *J Adol Health* 47:309-311. doi:10.1016
- Treuth M, Schmitz K, Catellier D, McMurray R, Murray D, Almeida M, Going, S, Norman J, and Pate R (2004) Defining accelerometer thresholds for activity intensities in adolescent girls. *Med Sci Sports Exerc* 36:1259-1266
- Trost S, Ward D, Moorehead S, Watson P, Riner W, and Burke J (1998) Validity of the computer science an application (CSA) activity monitor in children. *Med Sci Sports Exerc* 30:629-633
- Trost S, McIver K, and Pate R (2005) Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc* 37:S531-S543
- U.S. Department of Health and Human Services (USSDHHS) (2008) 2008 Physical activity guidelines for Americans. Washington, DC: Healthier US Gov

- Ward D, Evenson K, Vaughn, Rodgers A, and Troiano R (2005) Accelerometer use in physical activity: best practices and recommendations. *Med Sci Sports Exerc* 37:S582-S588
- Washburn R (2000) Assessment of physical activity in older adults. *Res Q Exerc Sport* 71:S79-S88
- Welk G (2005) Principles of design and analysis for the calibration of accelerometry-based activity monitors. *Med Sci Sports Exerc* 37:S501-S511
- Welk G, Blair S, Wood K, Jones S, and Thompson R (2000) A comparative evaluation of three accelerometry-based physical activity monitors. *Med Sci Sports Exerc* 32:S489-S497

APPENDIX A

SUBJECT CONSENT FORM

**SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY**

PROJECT TITLE: *A Comparison of Bilaterally Wrist-Worn Accelerometers on Measures of Free-Living Physical Activity in Adolescents*

Primary Investigators:

Edward M. Davila, Masters of Science Candidate,
Exercise Physiology
Phone: (406) 853-1275;
E-mail: edward.davila@msu.montana.edu
Dan Heil, PhD, Professor, Exercise Physiology Lab Director
Dept. of Health and Human Development, Movement
Science Laboratory
Montana State University, Bozeman, MT 59717-3540
Phone: (406) 994-6324; E-mail: dheil@montana.edu

PURPOSE OF THE STUDY:

The purpose of this study is to compare measures of physical activity during a 7 consecutive day period from wrist-worn activity monitors worn simultaneously on the left and right wrists. Standard protocol for using this particular brand of monitor states that the monitor be worn on the non-dominant wrist where dominance is defined as the hand preferred for writing. Our goal is to determine if measures of free-living physical activity are adequately measured on either wrist so that future studies can allow study participants to wear these monitors on either wrist.

If you agree to participate, you will be asked to wear two wrist-worn activity monitors, one on each wrist, during a 7 consecutive day period, 24 hours per day, while performing your usual daily activities. The activity monitors are battery powered and will collect information about the frequency and intensity of your body movements automatically so you will only need to wear the monitors. The expectations of all participants in this study are explained in detail on the following pages.

STUDY PROCEDURES:

If you agree to participate, you will meet twice with the investigator. The first meeting will be at the Movement Science Teaching Lab (MSTL) on the second floor of Romney Building on the campus of Montana State University whereas the second meeting will be at an agreed upon off-campus location. The first meeting will occur in the morning. During the first meeting, you will fill out paperwork (Consent Form), have demographic variables measured and/or recorded (body weight, body height, age, gender), and be fitted with two wrist-worn activity monitors (Actical monitor; Respironics Co, Bend, OR), each of

which are the size of a small wrist watch. The wrist monitor will be worn with a locking wrist band so that the monitor cannot be removed without cutting the wrist band. The band will be loose enough for comfort, but snug enough that the monitor cannot move freely around the wrist. Once locked, the wrist bands can only be removed by cutting the plastic straps. You will be given two extra plastic wrist bands in case a band size needs to be adjusted due to discomfort, or the original bands need to be replaced during the 7-day monitoring period. The activity monitors are water resistant and should be worn while showering, swimming, washing dishes, or any other water activities. You will also be given an activity log within which to record written descriptions of the type and duration of daily physical activity performed throughout the wearing period. After arranging a second meeting with the investigator, you will be asked to engage in your usual daily activities for the next 7 consecutive days. You are not being asked to alter your usual activities at home, work, or school. When you meet with the investigator for the second and last time in the late afternoon or early evening 8 days following the first visit, the monitors will be removed from both wrists by cutting the wrist straps with scissors. The investigator will ask you to provide your activity log that contains short written descriptions of the types and amount of activities engaged throughout the monitor wearing period. When this visit is complete, your assistance with project is concluded. Total meeting time with the investigator, both first (60 minutes) and second (15 minutes), will be about 75 minutes.

POTENTIAL RISKS:

There are no known risks associated with participation in this study.

BENEFITS:

There are no direct benefits for participants in this study. However, participants may request a summary of the study findings by contacting the primary investigator, Edward M. Davila, by phone (406-853-1275) or E-mail (edward.davila@msu.montana.edu).

STUDY PARTICIPANT COMPENSATION:

Participants will be offered \$20.00 compensation upon completion OR be offered the opportunity to donate the \$20.00 to the Bridger Ski Foundation.

CONFIDENTIALITY:

The data and personal information obtained from this project will be regarded as privileged and confidential. The information will not be released except upon your written request. 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.

FREEDOM OF CONSENT:

You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact Edward M. Davila, by phone (406-853-1275) or E-mail (edward.davila@msu.montana.edu), or the lab director Daniel P. Heil by phone (406-994-6324) or E-mail (dheil@montana.edu), to discontinue participation. *Participation in this project is completely voluntary.*

In the UNLIKELY event that your participation in this project results in physical injury to you, the investigators will refer you to a trained caregiver - No funds are available for such treatment. You are encouraged to express any questions, doubts or concerns regarding this project. The investigators will attempt to answer all questions to the best of their abilities prior to any testing. The investigators fully intend to conduct the project 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 406-994-4707.*

PROJECT TITLE: *A Comparison of Bilaterally Wrist-Worn Accelerometers on Measures of Free-Living Physical Activity in Adolescents*

STATEMENT OF AUTHORIZATION

Since you, the participant, are **less than 18 years of age** at the time this study, you MUST have the consent of a parent or legal guardian as indicated by their signature below.

I, *the parent or legal guardian*, have read the Informed Consent Document and understand the discomforts, inconvenience, and risks of this study. I,

_____ (*print name of parent or guardian*), related to the participant as _____ (*state relationship to participant*)

agree to the participation of _____ (*print name of participant*) in the project described in the preceding pages. I understand that I may later refuse participation in this study and that the participant, through his/her own action or mine, may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____ **Date:** _____

Participant's Assent Signature

Signed: _____ **Date:** _____

Parent or legal Guardian Signature

Signed: _____ **Date:** _____

Investigator Signature