The Assessment of Physical Activity and Sedentary Behaviors

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved November 2012 by the
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ARIZONA STATE UNIVERSITY

December 2012

ABSTRACT

The health benefits of physical activity are widely accepted. Emerging research also indicates that sedentary behaviors can carry negative health consequences regardless of physical activity level. This dissertation explored four projects that examined measurement properties of physical activity and sedentary behavior monitors. Project one identified the oxygen costs of four other care activities in seventeen adults. Pushing a wheelchair and pushing a stroller were identified as moderate-intensity activities. Minutes spent engaged in these activities contribute towards meeting the 2008 Physical Activity Guidelines. Project two identified the oxygen costs of common cleaning activities in sixteen adults. Mopping a floor was identified as moderate-intensity physical activity, while cleaning a kitchen and cleaning a bathtub were identified as light-intensity physical activity. Minutes spent engaged in mopping a floor contributes towards meeting the 2008 Physical Activity Guidelines. Project three evaluated the differences in number of minutes spent in activity levels when utilizing different epoch lengths in accelerometry. A shorter epoch length (1-second, 5-seconds) accumulated significantly more minutes of sedentary behaviors than a longer epoch length (60-seconds). The longer epoch length also identified significantly more time engaged in light-intensity activities than the shorter epoch lengths. Future research needs to account for epoch length selection when conducting physical activity and sedentary behavior assessment. Project four investigated the accuracy of four activity monitors in assessing activities that were either sedentary behaviors or light-intensity physical activities. The ActiGraph GT3X+ assessed the activities least accurately, while the SenseWear Armband and ActivPAL assessed activities equally accurately. The monitor used to assess physical activity and sedentary behaviors may influence the accuracy of the measurement of a construct.

DEDICATION

This entire doctoral program would not have been even remotely possible without the support of my friends and family. They carried me during the hard times, encouraged through the moments of doubt, and celebrated the successes. I have to thank the wonderful Samantha Fearer for her love, support, edits, and attention to detail. The countless hours spent on this document would not have been possible without the guidance of good music by the likes of: Griffin House, Mumford & Sons, Taylor Swift, the Avett Brothers, Ben Folds, and many others. This labor of educational excellence has been a worthwhile journey, and I thank my Lord and Savior, Jesus Christ, for the opportunity to complete it.

ACKNOWLEDGMENTS

This entire doctoral program could not have been undertaken without the immense amounts of thought, care, and teaching by Dr. Barbara Ainsworth. She has taken the time to mold me into the professional that I have become. Without an incredible mentor such as Dr. Ainsworth, I would not be half the professional that I am today. Her continuous push to improve my abilities, skills, and gifts have shaped me into a curious mind that pursues excellence. For this, I owe an immeasurable debt of gratitude.

I would also like to acknowledge my doctoral committee in shaping this dissertation through hours of discussion, revisions, and debate. This final product would not have been possible without the diligence and thought placed into it by Dr. Barbara Ainsworth (chair), Dr. Glenn Gaesser, Dr. Matthew Buman, Dr. Michael Belyea, and Dr. Christopher Wharton.

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Chapter 1

INTRODUCTION

Physical activity has significant health benefits. The research evidence collected over the past 50 years has shown that individuals who engage in regular moderate- and vigorous-intensity physical activity have lower mortality rates than sedentary individuals (Blair et al., 1996; Leon, Myers, & Connett, 1997; Morris & Crawford, 1958a; Patel et al., 2010). As well, dose-response relationships have been identified for the benefits of physical activity on reducing the risks for chronic disease conditions and for improving overall health (Blair et al., 1989; Nelson, Jennings, Esler, & Korner, 1986; Pitsavos et al., 2009; Rizzo, Ruiz, Oja, Veidebaum, & Sjöström, 2008).

Nearly 25 years ago, Caspersen, Powell, and Christenson (1985), defined terms used in the study of physical activity, including physical activity, exercise, and fitness. They defined physical activity as “any bodily movement produced by skeletal muscle that produces energy expenditure.” Physical activity serves as a broader construct to define the different types of movement, including exercise. Exercise is defined as “a structured program of activity that is designed to improve one or more components of physical fitness.” One common form of physical activity that is often used to promote health within an individual is structured walking or sports and exercise programs. Physical fitness is defined as “a set of attributes that are either health- or skill-related.” There is a preponderance of evidence to support structured walking and others forms of physical activity as a way to improve cardiovascular fitness in relation to health (Blair et al., 1996; Church, Earnest, Skinner, & Blair, 2007; Jakicic, Marcus, Gallagher, Napolitano, & Lang, 2003; Tjønna et al., 2009).

As the benefits of engaging in a regular physical activity have become more widely known, several organizations have issued recommendations or guidelines for the dose of activity needed to achieve health benefits (Haskell et al., 2007; Pate et al., 1995; USDHHS, 1996; USDHHS 2008). Within these guidelines are messages about the type, intensity, frequency and duration of activity required to improve metabolic processes associated with chronic diseases and illnesses, increase aerobic fitness, maintain or improve health status, and increase longevity. The first joint recommendations issued by a governmental agency and a private group were published in 1995 by the U.S. Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM). This statement provided a message for the public on the types of activity and intensities necessary to confer health benefits and prevent chronic disease. Individuals were advised to accumulate at least 30 minutes of moderate-intensity activity on most, but preferably all, days of the week (Pate et al., 1995). Moderate-intensity physical activity was defined as activities performed at 3 to 6 METs or roughly equivalent to walking at 3 – 4 miles per hour. The most recent recommendation for health-enhancing physical activity was released in 2008 by the United States Department of Health and Human Services (USDHHS) and recognized as the first federal guideline concerning physical activity for American adults (USDHHS, 2008). The guidelines state that Americans should accumulate at least 150 minutes per week of moderate-intensity physical activity, 75 minutes per week of vigorous-intensity activity, or an equivalent combination of moderate- and vigorous-intensity activity each week. Additional health benefits could be obtained by accumulating at least 300 minutes per week of moderate-intensity physical activity, 150 minutes per week of vigorous-intensity physical activity, or an equivalent combination of the two intensities. Furthermore, at least two days per week of strength training is recommended to maintain functional independence and support metabolic health. The guidelines also identified recommended activity levels for other populations to include older adults, children, pregnant mothers, and disabled individuals.

There are many activities individuals perform in daily life that may contribute to meeting the 2008 Physical Activity Guidelines but that have not been evaluated for their metabolic requirements. While the energy cost of many activities are presented in the 2011 Compendium of Physical Activities (Ainsworth et al., 2011), there are still estimated values for different activities such as: household and family care activities of mopping, cleaning bathrooms, doing dishes, and caring for children and elders. Projects one and two in this dissertation focus on measurement of the energy cost of these cleaning and family care activities using indirect calorimetry to determine metabolic equivalent values (METs).

Because regular physical activity has health enhancing effects, the promotion of physical activity has become a focal point for researchers and practitioners around the world. With a goal to have the most precise measurements possible, the ActiGraph accelerometer (ActiGraph, LLC, Pensacola, Florida, USA) is frequently used to determine the time spent in varying intensities of physical activity. Referred to as an objective activity assessment monitor, the ActiGraph has been used in national surveillance studies in the U.S. (National Health and Nutrition Examination Survey, NHANES) and Sweden (Hagströmer, Oja, & Sjöström, 2007) to assess the time spent in physical activity and sedentary behaviors (Matthews et al., 2008; Troiano et al., 2008). Traditionally, the ActiGraph sampling of movement has been integrated over one-minute into a score that summarizes the duration and intensity of movement over a period of time. While it is hypothesized that shorter integration periods, referred to as epochs, will reflect more time spent in inactive and light-intensity movement, little is known about the effect of shorter epochs, as frequent as 1-second, on the durations of varying intensities of movement times, including time spent in inactivity, light-, moderate-, and vigorous-intensity activities. Project three in this dissertation compared the effects of integrating ActiGraph data in epochs (1-, 5-, 15-, and 60-seconds) of varied duration on time spent in varying intensities of activity per day.

The fourth study in this dissertation focuses on the assessment of sedentary behaviors. Although the promotion of physical activity has been the dominant paradigm for health educators, recent attention has been given to the problem of excessive inactivity. While being physically active continues to be recommended for health, excessive inactivity seems to have unique health consequences independent of physical activity (Owen, Healy, Matthews, & Dunstan, 2010). With estimates of the number of Americans failing to meet the physical activity guidelines estimated at 95% with data obtained from accelerometry (Troiano et al., 2008) to 35% with data obtained from self-report methods (Carlson et al., 2008), there is a need to better understand how to assess and then reduce the amount of time people spend in sedentary lifestyle activities.

Many researchers have used the ActiGraph accelerometer to assess time spent in sedentary behaviors. However, questions exist about the validity of the ActiGraph to assess sedentary behaviors since older devices (e.g., GT1M) cannot differentiate between reclining, sitting, and standing postures (Carr & Mahar, 2012). Newer ActiGraph models (GT3X, GT3X+) contain an inclinometer that may increase the sensitivity to detect changes in body posture. Other devices also have been utilized to measure sedentary behavior such as the ActivPAL inclinometer and Polar Heart Rate monitor, but each of these devices have their strengths and disadvantages as well (Carr & Mahar, 2012). Integrated devices such as the Zephyr Bioharness and Actiheart have been utilized in research to assess time spent in sedentary behaviors (Adolph et al., 2011). The devices combine input simultaneously from different body systems, such as body acceleration and heart rate response to movement to identify activity scores (Brage N, Brage J, Franks, Ekelund, & Wareham, 2005; Brooks & Craven, 2012). However, evaluation of their utility to assess sedentary behaviors is limited. Since objective monitors are used so widely in physical activity and sedentary behaviors research, understanding how well different measures of physical activity compare with oxygen uptake, the criterion measured in this study, can advance the science of accurately assessing sedentary behavior. Such information is important because it may help to increase the sensitivity for studying the effects of sedentary behavior on health outcomes in epidemiological and clinical studies.

STATEMENT OF THE PROBLEM

A recurring problem in physical activity research is determining the optimal way to assess a specific behavior or set of behaviors. The Compendium of Physical Activities provides a guide for assigning MET intensities to activities. Yet, this guide must be continually updated by measuring the oxygen cost of physical activities performed and the resulting MET levels are not specific to people with different movement patterns, body masses, or ages (Ainsworth et al., 2011). Objective measures to assess physical activity are not without concerns. Using an electronic device to assess an activity or set of activities that the instrument is not designed to assess may result in inaccurate measures (Reilly et al., 2003). Within a device, a different internal setting may also trigger a difference in the accuracy of the measure. In accelerometers, for example, Edwardson and Gorely (2010) found that by changing the epoch length of ActiGraph accelerometers post-hoc, there were significant differences in amounts of time spent sedentary and in vigorous intensity activities. A committee gathered to discuss best practices in accelerometry advised that additional research needed to be conducted to determine optimal epoch length (Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005). As further research has been conducted, there have been recommendations on best practices in accelerometer research; however, there are no recommendations on epoch length in physical activity or sedentary behaviors research. Questions exist in the literature about the optimal epoch length for assessing physical activity and sedentary behaviors in accelerometry. Additionally, different devices have been used to assess sedentary behaviors, but there is scant evidence providing information on the best device for assessing sedentary behaviors. This dissertation has a theme of the assessment of physical activity and sedentary behaviors. Two studies are designed to update the Compendium of Physical Activities by measuring the oxygen cost of household cleaning chores and family care activities. The third study compares the effects of four ActiGraph epoch lengths on the assessment of time spent in varying intensities of physical activity and inactivity. The fourth study examines the accuracy with which different devices assess sedentary behaviors and light-intensity physical activity.

Hypotheses. Four projects were designed to utilize different devices to measure physical activities and sedentary behaviors. The research hypotheses for each project are listed below.

Project One. The Oxygen Cost of Selected Adult and Child Care Activities.

Purpose. To assess the oxygen cost of four care-related activities to enhance the 2011 Compendium of Physical Activities.

Project One Hypothesis. 1A. The oxygen cost of care activities will be in the light-to-moderate intensity range as determined by MET levels.

Project Two. The Oxygen Cost of Household Cleaning Activities

Purpose. To assess the oxygen cost of three household cleaning activities to enhance the 2011 Compendium of Physical Activities.

Project Two Hypothesis. 2A. The oxygen cost of household cleaning activities will be in the light-to-moderate intensity range as determined by MET levels.

Project Three. Assessing Activity Using Various ActiGraph Epoch Lengths.

Purpose 1. To determine the differences in minutes per day of light-, moderate-, and vigorous-intensity physical activity using an ActiGraph GT3X accelerometer with epoch lengths of 1-, 5-, 15-, and 60 seconds.

Purpose 2. To determine the differences in minutes per day of sedentary time using an ActiGraph GT3X accelerometer with epoch lengths of 1-, 5-, 15-, and 60 seconds.

Project Three Hypotheses. 3A. Shorter epoch lengths (less than 15-seconds) will result in greater minutes per day of light- and vigorous-intensity physical activity than a 15- or 60-second epoch length.

3B. A 60-second epoch length will result in fewer minutes per day of moderate-intensity physical activity than shorter epoch lengths.

3C. Shorter epoch lengths (less than 15-seconds) will result in greater minutes per day of total sedentary time than a 15- or 60-second epoch length.

Project Four. Assessing Sedentary Behavior with Multiple Measurement Devices.

Purpose. To assess the amount of time recorded as inactive and light intensity for seven activities using four objective measures of physical activity and energy expenditure.

Project Four Hypotheses. 4A. There will be no significant differences in the minutes of sedentary and light-intensity activities recorded by objective measurement devices when compared with oxygen uptake measured by indirect calorimetry.

SCOPE

This dissertation is a composite of four separate research projects with the overall theme of the measurement of physical activity and sedentary behaviors. The studies were designed to identify the oxygen costs of selected activities, to determine an optimal ActiGraph sampling rate (epoch length) to determine time spent in varying intensities of activities, and to compare the precision of different measurement devices on assessing sedentary behaviors in adults.

Assumptions.

1. The oxygen cost of activities will be accurately assessed via portable indirect calorimetry.
2. Participants accurately followed the placement of accelerometer belts and recorded non-wear time accurately on the log sheet.
3. Seven days of physical activity monitoring is an accurate measure of physical activity behavior in free-living conditions.

Limitations.

1. The convenience samples of adults in these studies limit the generalization of activity patterns and the energy costs of physical activities measures to the general population.

Significance of the Research.

In spite of the large amount of evidence that supports physical activity as a preventive measure for many chronic diseases, the American population is primarily inactive (Matthews et al., 2008). In order to accurately identify the prevalence of inactivity and reduce the sedentary behaviors, the tools used to measure inactivity must accurately assess sedentary behavior. This dissertation had a goal to increase understanding of the energy cost of various home and family care activities and identify the best ways to measure the time spent in sedentary behaviors and low-intensity physical activity by, 1) examining the oxygen costs of different activities of daily living; 2) examining the effect of varied epoch lengths on time spent sedentary and in different physical activity intensities and; 3) examining the accuracy in different measurement devices in assessing sedentary and light-intensity activities.

Definition of Terms.

1. Cardiorespiratory Fitness: A health-related component of physical fitness that relates to the ability of the circulatory and respiratory systems to supply oxygen during sustained physical activity (USDHHS, 1996).
2. Fitness: As a general construct, fitness is defined as: “A set of attributes that are either health- or skill-related” (Caspersen, Powell, & Christenson, 1985).
3. Epoch Length: The measurement time period used by an accelerometer to sum and store data (Trost, McIver, & Pate, 2005).
4. 1995 CDC-ACSM Physical Activity Recommendation: Adults should obtain $\geq$ 30 minutes per day of moderate-intensity physical activity (3-6 METs) on most, if not all, days of the week (R R Pate et al., 1995).
5. 1996 Surgeon General’s Report – Physical Activity Recommendation: Adults should accumulate at least 150kcal per day or 1,000 kcal per week of moderate- (3-6 METs) and or vigorous-intensity physical activity (> 6 METs) (USDHHS, 1996).
6. 2007 ACSM-AHA Physical Activity Recommendation: Adults age 18-65 need moderate-intensity physical activity for at least 30 minutes per day on five days each week or vigorous-intensity physical activity for at least 20 minutes on three

days each week. A combination of activity intensities can be performed to meet the recommendation (Haskell et al., 2007).

7. 2008 USDHHS Physical Activity Recommendation (Healthy Adults): Adults should accumulate at least 150 minutes per week of moderate-intensity activity, 75 minutes per week of vigorous-intensity activity, or an equivalent combination of the two intensities. Aerobic activity should be performed in bouts lasting at least 10 minutes in duration and spread throughout the week. Additional health benefits can be obtained by accumulating 300 minutes per week of moderate-intensity activity, 150 minutes per week of vigorous intensity activity, or an equivalent combination of both intensities. Strength training activities should be performed on the major muscle groups 2 or more days of the week ("Physical Activity Guidelines Advisory Committee Report.", 2008).
8. Metabolic Equivalent (MET): A MET is a unit used to estimate the oxygen consumption of physical activity. For the average adult, one MET equals the resting metabolic rate (sitting quietly), which is approximately 3.5 milliliters of oxygen per kilogram of body weight per minute (Ainsworth et al., 1993).
9. Oxygen cost: The amount of oxygen required to perform an activity at a selected intensity and duration (Kennard & Martin, 1984).
10. Physical Activity: Any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen et al., 1985).

Chapter 2

REVIEW OF THE LITERATURE

This chapter provides an overview of the health effects of physical activity and sedentary behaviors, recommendations and guidelines for physical activity, and the assessment of physical activity and sedentary behaviors. Attention is given to findings about the health effects of physical activity and sedentary behaviors obtained from observational studies and clinical trials.

Health Effects of Physical Activity and Sedentary Behaviors

The association between physical activity and health has been acknowledged for many years. Marcus Tullius Cicero declared in 65 BC that "It is exercise alone that supports the spirit and keeps the mind in vigor" (McCrory, 2007). The importance of physical activity as it pertains to health is evidenced by the numerous recommendations and guidelines issued by various organizations and governmental agencies over the past two decades. The goal of this section of the literature review is to examine the evidence obtained from epidemiological observational studies and from experimental clinical studies to identify an association between physical activity, sedentary behaviors, and health outcomes.

Observational studies. Much of the research laying the foundation for the physical activity and health evidence was performed in the 1950's and 1960's by Jeremy Morris and Ralph Paffenbarger. These two iconic names in physical activity research developed the field by demonstrating the need for physical activity to improve health and quality of life (Morris & Crawford, 1958b; Paffenbarger, Laughlin, Gima, & Black, 1970). In 1958, Jeremy Morris published the seminal work in the field, "Coronary Heart Disease and the Physical Activity of Work" (Morris & Crawford, 1958b). In this research study, Morris and Crawford examined the hospital records of 5,000 men in city hospitals that had died. Physicians categorized the cause of death with 3,800 classified as having died of causes other than coronary heart disease. The remaining 1,200 men died from various types of cardiovascular disease. Based on their last recorded occupation, individuals were classified into light-, moderate-, or heavy-activity categories. Individuals in the light activity category had twice as much ischemic myocardial fibrosis as individuals in the heavy category (13.4% and 6.8%). This was one of the first studies that created an evidence-based link between physical activity, physical inactivity, and risk for cardiovascular disease. By providing an epidemiological approach to this phenomenon, the field of physical activity research was initiated.

Following Jeremy Morris' seminal study, Ralph Paffenbarger identified the importance of physical activity at work and during leisure time. In the 1960's, Paffenbarger studied the effects physically active vs. sedentary occupations in the Longshoremen's Study (Paffenbarger et al., 1970). This 16-year longitudinal study examined the effects of work-related activity in an active and sedentary population that worked for the same corporation. Individuals who worked as cargo handlers (active work) expended 925 more calories per day on average than longshoremen (sedentary work). Additionally, sedentary workers had a sustained death rate from coronary disease that was 34% higher than the active workers ($p < .05$). A physically active job seemed to provide some protection from cardiovascular disease that was not afforded to the desk workers of the Longshoremen's Study.

In the 1970's Paffenbarger used data collected from the Harvard Alumni Study to assess the influence of leisure-time physical activity on health outcomes in nearly 50,000 male Harvard University graduates. Paffenbarger's seminal publication on leisure-time physical activity and heart attack risk included 16,936 males (age range = 35-74) and showed that individuals who expended less than 2,000 kilocalories per week in recreational activities had a 64% greater chance of heart attack than classmates who expended greater than 2,000 kilocalories per week (Paffenbarger, Wing, & Hyde, 1978). These data showed that increased activity in walking, stair climbing, and recreational activities lowered the incidence rate of having a coronary event.

In a follow-up report with the Harvard Alumni Study published in 1986, Paffenbarger, Hyde, Wing and Hsieh (1986) showed that regardless of smoking status, hypertension, age of parents' death, and other mitigating factors, relative risk of death was lowest in male Harvard alumni that were physically active at levels of >2,000 kilocalories expended per week versus those individuals who expended less than 2,000 kilocalories per week (relative risk = .72, 1.00)($p<.0001$). They concluded that even if additional risk factors for premature mortality might be higher than desirable, individuals that were more physically active had a lower relative risk for mortality compared to more sedentary individuals.

In the 1980's Leon et al. (Leon, Connett, Jacobs, & Rauramaa, 1987) published a series of studies showing the benefits of leisure time physical activity in men with cardiovascular disease risk factors on reducing all-cause mortality and disease-specific mortality in adults. The investigators followed men enrolled in the Multiple Risk Factors Intervention Trial (MRFIT) that was conducted to determine if changing coronary heart disease (CHD) risk factors (smoking, hypercholesterolemia, and hypertension) would reduce CHD mortality. The investigators assessed leisure time physical activity levels in the 12,138 middle-aged male MRFIT clinical trial participants at baseline and followed cause-specific and all-cause mortality outcomes for over 20 years. Using baseline data, participants were divided into 3 tertiles based on their minutes of physical activity per day: low (average 15 min/day), moderate (average 47 min/day), and high (average 134 min/day). After 7 years, there were 63% more fatal events related to CHD in the low duration group versus the moderate- and high-duration groups ($p < .01$). In the low duration group, there were also 70% more all-cause deaths than in the moderate- and high-duration groups ($p < .01$). There was no difference in CHD and all-cause death rates between the moderate- and high-duration groups ($p > .05$). Subsequent analyses at 10 years (Leon & Connett, 1991) and at 15 years following the baseline (Leon et al., 1997) showed results similar to the 7-year follow-up findings. The researchers concluded that there was a modest inverse relationship that existed between leisure time physical activity, CHD, and total mortality in men with pre-existing CHD risk factors.

Blair et al. (1989) analyzed the Aerobic Center Longitudinal Study (ACLS) to show a relationship between aerobic fitness and mortality risk. The ACLS is a prospective study examining the aerobic fitness levels and health and mortality outcomes of 10,224 men and 3,120 women. Each participant was given a maximal treadmill graded exercise test to assess their aerobic fitness levels. Aerobic fitness levels were divided into quintiles from the lowest duration to the highest duration by age and sex based on the time to fatigue on the treadmill graded exercise test. Participants were followed for 8 years to assess their mortality status. Using the highest fitness quintile as a referent group, relative risks for mortality were determined for each level of treadmill duration. The only significant difference observed was between the lowest fit group and the highest fit group in men (Relative risk = 3.44, CI = 2.05, 5.77) and between the two lowest fit and highest fit groups in women (Relative Risk for lowest fit group = 4.65, CI = 2.22, 9.75) (Relative Risk for second lowest fit group = 2.42, CI = 1.09, 5.37). A negative trend for mortality was observed from the least fit men to the most fit men (trend slope = -4.5, CI = -7.1, -1.9) and in the least fit women to the most fit women (trend slope = -5.5, CI = -9.2, -1.9). These trends indicated that the higher the fitness level of the participant, the lower the associated risk for mortality. The investigators concluded that higher levels of physical fitness provided a protective effect against death due to cardiovascular disease and all-cause mortality in this study.

Within these seminal studies, two themes emerged: spending more time in sedentary behaviors may be detrimental for health and that higher levels of physical fitness are associated with lower levels of mortality. Individuals who were engaged in sedentary occupations had a higher risk for mortality than their more active counterparts. Those who spent more time in recreational and transport activities had a lower risk for a heart attack than sedentary men. Men who were more physically fit had a lower risk for mortality than those men that were low fit. Physical activity and high fitness levels provide a protective effect against cardiovascular disease in many observational studies.

Randomized controlled studies. In order to better understand the relationship between physical activity and various health outcomes, randomized control studies are needed to identify how manipulating variables such as intensity and duration affect changes in physical activity, fitness and health outcomes. Such knowledge can provide better recommendations for interventions to promote higher levels of physical activity and improve health outcomes.

In the Dose Response to Exercise in Women (DREW) study, Church, Earnest, Skinner, and Blair (Church et al., 2007) developed multiple exercise protocols as part of a 6-month intervention to determine how little exercise is needed to increase physical fitness and modify CHD risk factors in women. Four conditions were compared: a control group that did not change activity level (n = 102), a group that expended 4 kcal/kg per week (n = 155), a group that expended 8 kcal/kg per week (n = 104), and a group that expended 12 kcal/kg per week (n = 103). Women trained at a heart rate equivalent to 50% of their peak VO_2. Mean amount of time spent exercising for each group was 72 minutes (4 kcal/kg group), 136 minutes (8 kcal/kg group), and 192 minutes (12 kcal/kg group). There were no significant differences in aerobic fitness levels between the groups at baseline. Results showed a significant trend in increased fitness levels with increased exercise duration as assessed by peak VO_2 in liters/minute (control = 1.28, 4 kcal/kg = 1.33, 8kcal/kg = 1.35, 12 kcal/kg = 1.39, $p < .001$). Results also showed a significant difference in the change in systolic blood pressure from baseline to the end of the study between the 4 kcal/kg group and the 12 kcal/kg group ($p=.02$). This indicated that there was dose-response effect in fitness level by exercise duration.

Jakicic, Marcus, Gallagher, Napolitano and Lang (Jakicic et al., 2003) studies the effects of altering exercise intensity and duration on aerobic fitness levels in a group of overweight, sedentary women (mean age = 37.0 years). Each participant was randomized to 1 of 4 groups: high intensity, high duration (n = 48); moderate intensity, high duration (n = 44); high intensity, moderate duration (n = 48); and moderate intensity, moderate duration (n = 44). The difference between moderate- and high-duration groups was determined by weekly caloric expenditure in exercise (1,000 kcal vs. 2,000 kcal). The exercise intensity was either moderate- (walking approximately 3 miles per hour) or vigorous-intensity (walking approximately 4.5 miles per hour). Walking was the prescribed method for meeting the exercise requirements. Each participant was provided a treadmill and given a target heart rate and a specific duration to adhere to for the protocol. Participants exercised 5 days a week for 12 months in this study. Participants were measured for aerobic fitness at baseline, 6 months, and at 12 months. Each group had a significant improvement in aerobic fitness across time ($p < .001$). Results showed no significant differences by exercise intensity ($p = .35$), by exercise duration ($p = .90$), or by the intensity and duration interaction ($p = .31$). The investigators concluded that improvements in aerobic fitness could be made at a moderate intensity for a moderate duration, and that high intensity exercise with a high duration is not necessary for improving aerobic fitness.

Investigators have compared how an intervention with an exercise program compares to a passive intervention that provides only advice on exercise. Tjønna et al. (2009) examined the effects of a structured exercise program versus a multidisciplinary approach of exercise, dietary, and psychological advice (MGT) on aerobic fitness. Participants (28 girls and 26 boys, mean age = 14 years) were randomized into either the exercise condition or the multidisciplinary condition. Participants in the exercise condition used a protocol consisting of a warm up, 4 x 4 minute aerobic intervals at 70% of maximum heart rate, and a cool down. The total exercise time was 40 minutes for two sessions per week. Participants received this treatment for three months with monthly follow-up sessions. The multidisciplinary group received counseling twice a month on dietary and exercise habits. There were no differences in maximal oxygen uptake (VO_2 max) between the two groups at baseline (32.3 ml/kg/min for both groups). The groups were significantly different at 3 months (32.3 ml/kg/min for MGT, 35.3 ml/kg/min for exercise, $p < .05$) and at 12 months (31.9 ml/kg/min for MGT, 36.0 ml/kg/min for exercise, $p < .05$). Even after the structured training had been removed, the exercise group had significantly higher VO_2 max levels than the MGT group. This confirms that after a formal exercise program has ceased, some of the training habits and cardiovascular benefits of the training remain.

Physical activity can be a beneficial part of a cardiac rehabilitation program after cardiac disease is diagnosed. Hambrecht et al. (2004) examined the effects of exercise in patients with stable coronary artery disease. Participants were randomized into either the experimental group, which received a structured exercise protocol, or the control group, which received the standard heart stenting procedure. The exercise protocol consisted of

20 minutes of cycling per day at 70% of each individual’s maximal heart rate. Participants cycled at home or at a gym for 6 days of the week and on the 7th day, participants attended a 60-minute exercise class at the hospital where the research was conducted. Results showed participants in the exercise group had a higher event-free survival (88% for exercise versus 70% for stenting) ($p = .023$), increased maximal oxygen uptake (22.7 to 26.2 ml/kg/min) ($p < .001$), and the exercise treatment cost less than half the stenting procedure ($p <.001$). An exercise program proved to be a cheaper, more-effective treatment in preventing relapse of cardiovascular disease and improving maximal oxygen uptake.

In summary, clinical trials have demonstrated that exercise training improves cardiovascular capability and aerobic fitness in both adults and adolescents. Moderate intensity activity can improve aerobic fitness in older women, therefore dispelling the myth that only vigorous intensity activity improves aerobic fitness. Individuals rehabilitating from heart disease can also increase their odds for survival with exercise training as compared with surgical procedures.

Sedentary Behaviors

The study of the impact of sedentary behaviors on health outcomes is an emerging paradigm within the field of physical activity and health. Independent of physical activity levels, excess sedentary behaviors carry unique health risks such as decreased lipoprotein lipase activity (Hamilton, Healy, Dunstan, Zderic, & Owen, 2008), increased adiposity (Hamilton, Hamilton, & Zderic, 2007), and impaired glucose tolerance (Healy et al., 2007a). While physical activity can attenuate some of the adverse health effects from sedentary behaviors, individuals who fail to meet guidelines for physical activity of 150 min/day or greater and self-report sitting at least six hours per day are at nearly twice the mortality risk as individuals that meet the physical activity guidelines and self-report less than three hours per day of sitting time (Patel et al., 2010). While a significant amount of literature on the health benefits of physical activity exists, the field of sedentary behaviors and its effects on health are only beginning to be explored.

Observational studies. A recent PubMed search of the terms "sedentary" and "health behaviors" returned 1,539 articles on the topics. However, sedentary behaviors and health outcomes are not the primary outcome measure for many of these articles. The studies below outline some of the observations that have been made about the prevalence of sedentary behaviors and the impact of sedentary behaviors on health outcomes.

Prevalence of sedentary behaviors. Results from the American Time Use Survey (ATUS) were used to identify the prevalence of sedentary behaviors in U.S. adults. The ATUS is a telephone survey conducted annually to randomly selected individuals to measure the amount of time Americans spend performing different activities each day. Among the 79,652 individuals queried from 2003-2008, Tudor-Locke, Johnson, and Katzmarzyk (Tudor-Locke, Johnson, & Katzmarzyk, 2010a) reported that 96% of Americans reported spending time daily in the sedentary behaviors of eating and drinking, while only 2% reported spending time in vigorous activity on cardiovascular machines at a gym.

In another study utilizing data from the 2003-2009 American Time Use Surveys, Tudor-Locke, Leonardi, Johnson, and Katzmarzyk, (2011) reported data from 30,758 individuals that showed individuals working in sedentary occupations reported 11 hours per day of sedentary time excluding time spent sleeping. This high amount of time spent sedentary allowed for little time to meet the physical activity recommendations. They concluded that individuals in sedentary occupations may be a target population for worksite activity interventions.

Recent evidence from the 2003-2004 National Health and Nutrition Survey (NHANES) showed differences in physical activity levels between self-report survey and accelerometer assessment methods (Ham & Ainsworth, 2010). Using a cross-sectional design of participants from the 2003-2004 NHANES accelerometer database and a sample of adults completing the 2010 Healthy People Midcourse Review for physical activity behaviors. Self-report measures of physical activity were compared to objective measures of physical activity to determine the proportion of adults who met the Healthy People 2010 Physical Activity Guidelines. NHANES data were analyzed in 3,043 individuals (n = 1,476 men, n = 1,567 women, ages 18-75). Based on accelerometer data, Mexican-Americans were significantly more active than Non-Hispanic Whites and Non-Hispanic Blacks (26.9%, 19.7%, 15.3%, $p < .05$). The authors concluded that physical activity disparities differed from other studies.

Matthews et al. (2008) assessed the amount of time adults in the United States spent in sedentary behaviors by using accelerometer data from the 2003-2004 NHANES database. Participants included 6,239 individuals (n = 3,120 men, n = 3,209 women, age range = 6-85) who wore ActiGraph model 7164 accelerometers for at least 10 hours on one day. Using a cut-point of 100 counts per minute, on average, males spent 7.63 hours per day in sedentary behaviors, while females spent 7.70 hours per day in sedentary behaviors ($p = .001$). This amount of time equated to 54.9% of measured time spent sedentary on a daily basis. These data suggest that a large portion of the average American day is spent in sedentary behaviors.

Levine, Schleusner, and Jensen (2000) suggested that the key to increasing overall activity levels involves increasing light intensity physical activity through the reduction of time spent in sedentary behavior. Participants included 24 adults (17 female, 7 male) whose fidgeting behaviors were monitored while seated. Energy expenditure was higher in those who fidgeted than those who did not fidget while seated (8.2 kJ to 5.4 kJ, $p < .001$). The investigators concluded that small amounts of movement, such as fidgeting while seated may be a way to negate some of the metabolic consequences of sedentary behaviors.

Sedentary behaviors and the metabolic syndrome. There is an emerging literature that has examined the effects of sedentary behavior on the components of metabolic syndrome: blood pressure, fasting glucose, waist circumference, elevated triglycerides, and decreased high density lipoprotein cholesterol (Sisson et al., 2009). Many researchers have reported that increased amounts of time spent sedentary are associated with negative cardiometabolic outcomes such as increased waist circumference and increased insulin resistance (Healy, Dunstan, et al., 2008; Healy, Wijndaele, et al., 2008; Helmerhorst, Wijndaele, Brage, Wareham, & Ekelund, 2009; Lynch et al., 2010; Sisson et al., 2009; Wijndaele et al., 2010).

Sisson et al. (2009) analyzed data from 2003-2004 NHANES to assess the relationship between time spent in sedentary behaviors and the metabolic syndrome. Of the 3,556 individuals included in the analysis (men, n=1,868, mean age = 45.1 $\pm$ 0.6; women, n=1,688, mean age = 47.9 $\pm$ 0.6), men who engaged in leisure time sedentary behaviors greater than 4 hours per day had a 2-fold increase in likelihood of having metabolic syndrome as compared with men reporting less than one hour per day of leisure time sedentary behaviors (OR = 1.94; 95% CI = 1.25, 3.04). In females, but not men, meeting the physical activity guidelines of 150 min/day of moderate-vigorous physical activity attenuated this effect (OR = 1.62; CI = 0.87, 3.01). The researchers concluded that in men, high levels of self-reported sedentary behaviors, regardless of physical activity levels, increased one's risk for metabolic syndrome.

Time spent in objectively measured sedentary behaviors has also been associated with increased waist circumference (Healy, Wijndaele, et al., 2008; Lynch et al., 2010). The investigators enrolled 169 pre-diabetic individuals (n=67 men, n=102 women, age range = 30-87 years) in a cross-sectional metabolic syndrome screening study. Participants had their waist circumference measured and wore an ActiGraph 7164 accelerometer for seven days. The following accelerometer cut-points were used to determine sedentary behaviors and activity levels: sedentary behavior (<100 counts per minute) (Matthews et al., 2008), light intensity (100-1951 counts per minute), moderate intensity (1952-5724 counts per minute), and vigorous intensity (>5724 counts per minute) (Freedson, Melanson, & Sirard, 1998). Results showed a 3.1cm increase in waist circumference for each 10% increase in time spent in sedentary behaviors (B = .22; CI = .09-.36). There was also a significant negative association between waist circumference and moderate-vigorous intensity activity (B = -0.16, CI = -.34, -.004). The authors concluded that spending more time in sedentary behaviors was associated with an increased waist circumference and spending more time engaged in moderate-vigorous intensity activity was associated with lower waist circumference.

In a larger population, Healy, Matthews, Dunstan, Winkler, and Owen (2011) examined the 2003-2004 and 2005-2006 NHANES databases for associations between breaks in sedentary time and markers of metabolic syndrome in 4,757 individuals. A break in sedentary time was considered to be any instance of the accelerometer recording over 100 counts in a single minute. After accounting for total sedentary time, moderate-intensity physical activity, and vigorous-intensity physical activity, the researchers found that breaks in sedentary time (any counts over 100 for 2 consecutive minutes) were inversely associated with waist circumference ($p < .001$) and c-reactive protein ($p = .001$).

One of the limitations with the studies reported by Healy et al. (2010; 2011) is that a 60-second epoch length (ActiGraph GT1M) was used to assess physical activity and sedentary behaviors. With the ActiGraph GT3X, Kozey-Keadle et al. (2011) showed that a cut-point of 150 counts per minute is more accurate for assessing sedentary behavior than cut-points of 50- or 100 counts per minute. When Kozey-Keadle et al. compared the output of the ActiGraph to direct observation, the cut-point of 100 counts per minute had a weak association in assessing sedentary time ($R^2 = .39$). The 150 counts per minute cut-point demonstrated the lowest bias of the ActiGraph cut-points (1.8%). The authors concluded that when conducting research on sedentary behavior with the ActiGraph GT3X, a cut-point of 150 counts per minute should be used.

Lynch et al. (2010) examined 111 self-reported female breast cancer survivors from the 2003-2004 and 2005-2006 NHANES data to determine the relationship between objectively assessed sedentary behavior and markers of obesity. This cross-sectional study utilized ActiGraph 7164 accelerometers to assess physical activity and sedentary behaviors. The following cut-points were used to assess levels of physical activity and sedentary behaviors: inactive (0-100 counts per minute), light intensity (100-1951 counts per minute), and moderate-vigorous intensity physical activity (>1951 counts per minute). Moderate-vigorous intensity activity was negatively associated with waist circumference (B = -9.805; CI = -15.836, -3.775). However, time spent in sedentary behaviors was not significantly associated with waist circumference in this population (B = 2.687; CI = -0.537, 5.910). The authors concluded that decreasing time in sedentary behaviors and increasing moderate-vigorous intensity physical activity could be beneficial in weight management.

The association between sedentary behaviors and adverse metabolic risk factors for CHD and type 2 diabetes was examined in the Australian Diabetes study (Healy, Dunstan, et al., 2008). Sedentary behaviors were measured using an ActiGraph model 7164 accelerometer. Subjects included 168 pre-diabetic adults (n= 65 men, n= 103 women, mean age = 53.4). Results showed that, independent of moderate-to-vigorous physical activity, increased amounts of time spent in sedentary behaviors, was negatively associated with waist circumference (B = -0.16, CI = -0.31, -.02; p = .026), body mass index (BMI) (B = -0.19, CI = -0.35, -.02; p = .026), triglycerides (B = -0.18, CI = -0.34, -0.02; p = 0.029), and 2-hour plasma glucose levels (B = -0.18, CI = -0.34, -0.02; p = .025) The authors concluded that increased amounts of time spent sedentary increased the risk factors for metabolic syndrome.

Helmerhorst, Wijndaele, Brage, Wareham and Ekelund (2009) studied 166 men and 210 women (mean population age = 49.4) as part of the Medical Research Council Ely Study to examine the association between sedentary time and fasting insulin levels. Time spent in sedentary behaviors was recorded using a heart rate monitor over 4 days. Sedentary time was determined by the flex heart rate method and moderate-to-vigorous intensity physical activity was calculated as any heart rate over 1.75 times the individual resting heart rate. Participants were followed for 5.5 years after baseline activity monitoring. Results showed that, independent of moderate-to-vigorous physical activity levels, increased amounts of sedentary time were associated with increased fasting insulin levels (B = .004, CI = .0009, .006; p = .0009). The authors concluded that individuals with higher levels of sedentary time may be at an increased risk for developing type 2 diabetes.

Not all studies report positive associations between sedentary behaviors and adverse markers for the metabolic syndrome. Ekelund, Brage, Griffin, and Wareham (2009) enrolled 192 individuals, (n = 81 men, n = 111 women) in a study to measure activity levels and metabolic variables at baseline and at a 1-year follow-up period. The

ActiGraph 7164 accelerometer was used to assess physical activity and sedentary behaviors. Accelerometer cut-points were: sedentary behavior (<100 counts per minute) (Matthews et al., 2008), light intensity (100-1951 counts per minute), moderate intensity (1952-5724 counts per minute), and vigorous intensity (>5724 counts per minute) (P S Freedson et al., 1998). A homeostatic model assessment of insulin resistance (HOMA-IR) score was calculated to reflect insulin control. Time spent in sedentary behaviors was not significantly associated with HOMA-IR score at baseline (B = .0004, CI = =.0006, .001; p = .42) or at a 1-year follow-up period (B = .001, CI = -.002, .00004; p = .21). However, a significant association between moderate-to-vigorous intensity physical activity and HOMA-IR score was reported (B = -.004, CI = -.008, -.00001; p = .048). The authors recommended that an emphasis be placed on increasing moderate-to-vigorous physical activity for a reduction in HOMA-IR score and insulin resistance.

Rizzo, Ruiz, Oja, Veidebaum, and Sjostrom (Rizzo et al., 2008) used a cross-sectional design to examine the relationship between low-to-high physical activity levels and insulin resistance. 613 participants (n = 261 boys, n = 352 girls, mean age = 15.5 $\pm$ 0.5 years) were selected for analysis from the European Youth Heart Study. Physical activity levels were assessed using accelerometry, body fat was assessed using skinfold calipers, and insulin resistance was calculated using fasting glucose and fasting insulin levels. Activity levels were divided into levels of low (<1.5 METs), moderate (3 – 6 METs), and high (> 6 METs). Individuals classified as moderately active had significantly lower insulin levels than individuals classified as low active (B = -.00142, p = .004). Individuals classified as high active had significantly lower insulin levels than low active individuals (B = -.00526, p < .001). The authors concluded that an increase in moderate-to-vigorous physical activity would mitigate the effects of increased insulin resistance.

There is currently not enough information to determine if a reduction of total sedentary time is associated with positive outcomes in the reduction of insulin resistance. However, evidence is accumulating which shows that a reduction in sedentary behaviors may be effective in reducing the incidence of metabolic syndrome. While recommendations have been made to increase physical activity as part of controlling or reducing the metabolic syndrome (Grundy, 2006), there are no recommendations to date to limit time spent in sedentary behaviors for metabolic syndrome prevention or management.

Sedentary behaviors and mortality. The effects of sedentary behaviors on all-cause and cause-specific mortality is in its infancy as a field of study (Bellocco, Jia, Ye, & Lagerros, 2010; Katzmarzyk, Church, Craig, & Bouchard, 2009; Patel et al., 2010). Katzmarzyk, Church, Craig, and Bouchard (2009) reported the findings of the effects of self-reported sitting time on all-cause mortality using data from the Canadian Fitness Survey. These data were representative of Canadians across the country. In this 12 year prospective study, 17,013 individuals ($n = 7,278$ men, $n = 9,735$ women, age range = 18-90) reported sitting time on a questionnaire. Individuals were classified into five categories of sitting time based on the amount of self-reported daily sitting time (almost none of the time, one fourth of the time, half of the time, three fourths of the time, and almost all the time). Participant all-cause mortality was assessed over a 12-year follow-up. 1,892 individuals died during the course of the study. The authors reported a significantly higher all-cause mortality rate for those who sat almost all the time as compared with individuals who sat almost none of the time. There was no difference in all-cause mortality for sitting-times for those who sat for a longer duration as compared with the referent category (Hazard Ratio = 1.00, 1.00, 1.11, 1.36, 1.54; trend $p < .0001$).

The authors concluded that individuals who reported sitting all the time during the day could be at risk for early all-cause mortality.

In a 14-year prospective study, Patel et al. (2010) examined 123,216 individuals (n = 53,440 men, n = 69776 women, age range = 50-74) from the American Cancer Society's Cancer Prevention Study II Nutrition Cohort. The purpose of the study was to assess the relationship between time spent sitting and in physical activity during leisure time and all-cause mortality. Using a self-report physical activity survey and all-cause mortality from death records, both physical activity and time spent sitting were categorized into tertiles of low, medium and high levels. Based on levels of physical activity and sitting time, 9 categories for classification combinations of activity and sitting time of individuals were developed. Using the high-active, low-sitting group as the referent group (relative risk = 1.0), as compared with the referent group, the relative risk for the low-active, high-sitting group was 1.94 (CI = 1.70 – 2.20) for women and 1.48 (CI = 1.33 – 1.65) for men. Those who reported sitting all the time had a 16% lower survival rate than those who reported sitting none of the time ($p < .0001$). The authors concluded that having low leisure time physical activity and high sedentary time increases the risk for all-cause mortality across gender, but is especially hazardous for women.

Bellocco, Jia, Ye, and Lagerros (2010) examined the effects of sedentary behaviors on mortality in a prospective population of Swedish adults from the Swedish National March Cohort. 40,729 individuals (n = 14,585 men, n = 26,144 women, age range = 7-94) were followed for 10 years to determine cause-specific risks for mortality. Individuals self-reported body mass index, waist circumference, waist to hip ratio, and physical activity levels in a 32-page survey. Participants recorded the mean amount of weekly time spent in nine different categories related to work, leisure time, and time spent in sedentary behaviors. Sedentary men (Hazard Ratio = 1.0) were at an increased risk for all-cause mortality as compared to those who were moderately active (Hazard Ratio = .82 CI = .71 - .94, $p = .016$) or highly active (Hazard Ratio = .82 CI = .71 - .95, $p = .016$). Being physically inactive and having a BMI greater than 30 in men was associated with a 98% (CI = 31%, 208%) increase in the likelihood of all-cause mortality over a 10 year period. The authors concluded that being sedentary and having increased markers of obesity increased the likelihood of premature death.

Sedentary behavior and markers of cardiovascular disease. Kozakova et al. (2010) examined the effects of objectively measured sedentary behavior on carotid intimamedia thickness over a 3-year period. 614 individuals had their carotid intimamedia thickness measured by B-mode carotid ultrasound and their physical activity and sedentary behaviors were assessed by an ActiGraph 7164 over a period of seven days. Sedentary behaviors were calculated as: < 100 counts per minute (Matthews et al., 2008). Activity was measured as: light-intensity as 100-1951 counts per minute, moderate-intensity as 1952-5274 counts per minute, and vigorous-intensity as > 5724 counts per minute (Freedson et al., 1998). Results from the study showed that those who engaged in vigorous physical activity was associated with a slower pace of increased intimamedia thickness versus individuals who engaged in moderate intensity physical activity (7 micrometers versus 19 micrometers, $p<.05$). These findings were in spite of the vigorously-active group having a higher ratio of sedentary behavior (Kozàkovà et al., 2010). The thickening of the intimamedia was associated with increased atherosclerosis, a risk factor for cardiovascular disease. The authors concluded that engagement in vigorous intensity activity reduced the deleterious effects of a highly sedentary life.

In summary, the data from the aforementioned studies show that high levels of sedentary behaviors and low levels of physical activity significantly increase risks for the metabolic syndrome, cardiovascular disease, and premature mortality. Traditionally, the approach to reducing such risks has been to increase physical activity. While this approach is still important, reducing total sedentary time should be considered as an effective approach in reducing the metabolic syndrome, cardiovascular disease outcomes, and risk for mortality. Reducing sedentary behaviors is possible by replacing some of one's daily sedentary time with light-, moderate-, or vigorous activity. Further research needs to be conducted to determine if interventions reducing sedentary time alone or in combination with increased intentional physical activity will decrease risk for cardiovascular disease and mortality. Seeking reductions in sedentary time should also be considered when writing public health policy as a way to reduce the risks for all chronic diseases.

Physical Activity Recommendations

Physical activity recommendations are created to provide a guideline for children and adults to obtain the optimal dose of physical activity for health promotion and disease prevention. The section below outlines the history of physical activity recommendations and provides an overview of the current physical activity recommendations and guidelines in the United States and globally.

ACSM recommendations. The American College of Sports Medicine (ACSM) has a focus of improving the health of individuals through the promotion of physical activity. ACSM has been at the forefront of synthesizing research about the amount and types of activity needed to obtain health benefits. The earliest position statement issued by the ACSM was published in 1975. The emphasis of this recommendation was on performing exercise to improve physical fitness. The "Guidelines for Graded Exercise Testing and Prescription" stated that individuals should exercise at 70-90% of their heart rate maximum, for 20-45 minutes per day, 3-5 days per week (ACSM, 1975). Subsequent revisions to the ACSM recommendations in 1980 (ACSM, 1980) and 1986 (ACSM, 1986) changed the amount of time and intensity in exercise recommended to 15-60 minutes per day, at an intensity of 70-85% of heart rate maximum, 3-5 days per week. In 1990, ACSM lowered the prescribed intensity to 60-85% of heart rate maximum, with the duration and frequency remaining the same as the 1980 and 1986 recommendations (ACSM 1990).

1995 CDC-ACSM physical activity recommendations. With the beginning of the 1990's, physical activity became a leading concern for public health (Pratt, Epping, & Dietz, 2009). In 1995, ACSM and the U.S. Centers for Disease Control and Prevention (CDC), issued a joint statement on physical activity and public health (Pate et al., 1995). The purpose of this statement was to provide the public with a message about the frequency, intensity, and duration of physical activity needed to achieve health benefits and disease prevention. The key point made in this statement was that "healthy adults should accumulate 30 minutes or more a day of moderate intensity physical activity on most, if not all, days of the week." The use of the phrase moderate-intensity activity proved to be one of the largest paradigm shifts from the previous physical fitness goals that focused on vigorous-intensity exercise. A moderate-intensity activity was described as 3-6 METs. An example of such an activity is a sustained walk at 3 miles per hour (Ainsworth et al., 2011). A second point from this statement was, "that activity could be accumulated in short bouts of 8-10 minutes that would contribute to the final daily tally of moderate intensity activity." Even through these multiple bouts of activity, health benefits and disease prevention could still be achieved.

1996 surgeon general's report (SGR). After the release of the CDC-ACSM physical activity recommendation in 1995 (Pate et al., 1995), the U.S. Surgeon General issued a report in 1996 recommending regular physical activity for health (USDHHS, 1996). This report emphasized the benefits associated with moderate- and vigorous-intensity activity with the recommended amount defined using caloric expenditure. The SGR recommended adults expend at least 150 calories per day or 1,000 calories per week in moderate- or vigorous-intensity activity. Additional caloric expenditure in the form of vigorous activity was acknowledged as being beneficial, but not necessary for health benefits. The report also was instrumental in providing an overview of the literature demonstrating that regular physical activity can reduce the risk of developing chronic diseases such as diabetes, hypertension, and coronary heart disease, aid in maintaining healthy bones, joints, and muscles, and improve mental health.

2007 ACSM-AHA recommendations. In 2007, an update to the previous CDC-ACSM recommendation (Pate et al., 1995) was performed by the ACSM and the American Heart Association (AHA) (Haskell et al., 2007). This update was important because it provided evidence-based guidelines for physical activity, clarified the statement made in the CDC-ACSM 1995 recommendations of "most days of the week" (Pate et al., 1995), and it addressed the value of vigorous-intensity physical activity. The report recommended that "healthy adults accumulate 30 minutes per day of moderate-intensity activity on 5 days of the week or 20 minutes per day of vigorous intensity activity on 3 days of the week". It was also noted that a combination of moderate-intensity and vigorous-intensity activity can be used to meet the guidelines. Additionally, the authors noted that further health benefits can be conferred by exceeding the recommended amounts of activity and healthy adults should engage in strength training at least 2 days of the week. Thus, this update is important because it increased the scope of the recommendations from moderate-intensity activity only to add strength training, vigorous-intensity activity, and that additional health benefits could be accrued with increased amounts of activity.

2008 U.S. federal guidelines. In 2008, the United States federal government issued the first set of guidelines for physical activity called the "Physical Activity Guidelines for Americans" (USDHHS, 2008). Unlike previous physical activity recommendations which had focused on healthy adults, the "Physical Activity Guidelines for Americans" issued guidelines for children, older adults, and other special populations. The message of the Physical Activity Guidelines were similar to the 2007 recommendations from the ACSM-AHA, however, the emphasis was placed on weekly accumulation of time spent in moderate-intensity activity with a stated goal of 150 minutes per week or by engaging in vigorous intensity activity for 75 minutes per week, or a combination of moderate and vigorous intensity activity. Doubling the amount of minutes was purported to increase health benefits. There was no recommendation for the minimum frequency needed because evidence from Lee, Sesso, Oguma, and Paffenbarger (2004) showed that men who accumulated their activity in 1-2 days of the week versus 5 days per week had no differences in mortality.

World Health Organization. In 2010, the World Health Organization (WHO) issued a set of recommendations for the amount of physical activity for optimal health. Using the information from previous recommendations, the WHO recommended that healthy adults accumulate 150 minutes per week of moderate-intensity physical activity, or 75 minutes of vigorous-intensity activity, or a combination of the two intensities (WHO 2010). Additionally, it was recommended that bouts of activity be at least 10 minutes in duration to be counted towards meeting the recommendations. Individuals were also encouraged to reach 300 minutes per week of moderate-intensity physical activity, or 150 minutes of vigorous-intensity activity, or a combination of the two intensities to receive additional health benefits. The WHO recommendation also recommended that strength training exercises should be performed on 2 or more days of the week.

Assessment of Physical Activity

Physical activity has been assessed using many different measures, but the two primary methods are subjective and objective measures. These two methods are detailed below.

Subjective measures. Physical activity has historically been assessed using subjective self-reported measures of physical activity. Within the realm of subjective assessment, there are two types of measurement methods: questionnaires (global assessment, short recall, and quantitative history) and logbooks and records (LaMonte & Ainsworth, 2001). These methods are relatively inexpensive to administer, are easy to disperse to a large population, and can lend context to physical activity patterns.

Global recall. Global assessments are short questionnaires, typically 1-4 questions in length, designed to be administered to large populations. An example of a global assessment is the questionnaire used in the National Center for Health Statistics (NCHS) survey to determine the physical activity levels of thousands of individuals across the United States (Slater, Green, Vernon, & Keith, 1987). This global questionnaire was designed to assess overall activity level across occupation and leisure. The benefit of using this sort of questionnaire is that it determined physical activity throughout the day in different forms. However, like the other subjective measures, it does not tend to accurately reflect an individual's day to day activity.

Recall questionnaire. Short-recall questionnaires are most frequently used to assess physical activity in epidemiologic studies to relate physical activity with health-related outcomes. Recall questionnaires typically have 10-20 items and allow fairly specific assessment of frequency, duration, and types of physical activity during the past day, week, or month (LaMonte & Ainsworth, 2001).

A recall assessment asks the participant to think back for a certain time period and report if they had engaged in any physical activity. An example of this is the 2001 Behavioral Risk Factor Surveillance System (BRFSS) (Macera et al., 2001). The BRFSS asks the participant questions about usual moderate- and vigorous-leisure and transportation activity participation. A participant is then classified according to the activity levels from inactive to meeting the CDC-ACSM physical activity recommendations.

The items from short-recall questionnaires often are scored in ordinal format (low to high levels of physical activity) (Baecke, Burema, & Frijters, 1982), summary data indices (exercise units) (Sidney et al., 1991), or in a summed score of continuous data ($Kcal \cdot kg^{-1} \cdot day^{-1}$) (Blair et al., 1985). The data from these instruments can be used to identify individuals that are not meeting physical activity guidelines, individuals that have changed behavior to meet physical activity guidelines, or individuals that should be targeted for future physical activity interventions.

Quantitative history. A quantitative history assessment is different in that it attempts to actually gauge the activities that an individual has performed over a longer period of time in the past. Ainsworth, Jacobs, Leon, Richardson, and Montoye (1993) used a quantitative history questionnaire called the Tecumseh Self-Administered Occupational Questionnaire to assess physical activity habits at work during the past year. For each question that a participant acknowledged engaging in regularly, the participant was asked to quantify how much time per week they engaged in the task. The advantage of using this method was that the researchers were able to identify different activities an individual performed, the duration of those activities, and then give a composite activity score to group participants. This method is not without flaws in that individuals may not accurately assess their intensity during an activity or the duration that they performed this activity.

In summary, while physical activity questionnaires are easy to use, have low participant burden, and are generally inexpensive, one of the limitations of using recall questionnaire derived self-report data is that physical activity levels are often over-reported. Individuals have a tendency to estimate physical activity levels higher than what objectively-assessed data would indicate. Data from these recall questionnaires can have associated error levels ranging from 35-50% for the recalled activities (Lagerros & Lagiou, 2007). This over-reporting must be considered when selecting a recall questionnaire.

Logbooks, records, and diaries. Physical activity records, logbooks, and diaries are used to assess the quantity (duration) and quality (type) of physical activities in an individual. Physical activity records and diaries are used to keep a record of all physical activities as they occur or at specific time intervals (e.g. every 15 minutes). The Ainsworth Physical Activity Record (Ainsworth et al., 2000) has participants record each activity that is performed over the course of a day. Participants record the time the activity began, the body posture of the activity (reclining, sitting, standing, or walking), a written description of the activity, the intensity of the activity (light, moderate, vigorous), and the activity category (for classification purposes). The activities of each individual can then be assigned a MET value using the Compendium of Physical Activities (Ainsworth et al., 2011; LaMonte & Blair, 2006; Washburn, Heath, & Jackson, 2000). Using this information, patterns of physical activity can be better understood. This method is time-intensive for the participants having to record each activity. In addition, the researcher has to code each activity, which is also time intensive. Because of the detailed nature of these records, they are considered to be the criterion measure for subjective physical activity assessment (Conway, Seale, Jacobs, Irwin, & Ainsworth, 2002).

Logbooks differ from records in that they provide a detailed list of activities that may have been performed in the past day. Individuals check off any activity on the list that was performed during each day and in some logbooks, recall the time spent in the activity. While this is a lighter participant burden than records, there may be activities performed that were not on the list provided to the participant, such as rollerblading or swimming (Lagerros & Lagiou, 2007). Additionally, participants' behavior may be altered by logbooks and records because of the increased awareness of physically active behaviors. An example of a logbook assessment is the Bouchard 3-day physical activity record (Bouchard et al., 1983). Each day is divided into 15-minute periods and an individual is asked to record what activities were performed during each interval. Individuals can choose from a list of pre-selected activities to record a corresponding number in the logbook. This recording is typically performed using two weekdays and one weekend day.

Like all subjective measures of physical activity, an individual may be biased to report being more physically active than he or she actually is in order to achieve a level of social acceptability. Other individuals may not be able to accurately assess the amount of time spent performing a certain task, or they may misclassify an activity or the intensity of the activity. Logbooks and physical activity records are useful in studies when an investigator is interested in profiling the daily activity of individuals. Many researchers may prefer logbooks and records because they are non-invasive and require that a participant record only activities performed.

Objective Measures. Objective measures of physical activity assess duration and intensity of physical activity and sedentary behaviors. Some devices measure certain domains more accurately than others. Different types of objective measures will be discussed in the section below.

Accelerometers. As the science of physical activity has progressed, more accurate, objective measures have been used to quantify physical activity. One of the most often used objective measures of physical activity is the accelerometer. An accelerometer is able to assess both the intensity and duration of physical activities. A recent (February, 2012) PubMed search of the key terms “physical activity” and “accelerometer” yielded 1,136 unique articles. One of the most frequently used brands of accelerometers in physical activity research is the ActiGraph (ActiGraph, LLC, Pensacola, Florida, USA). ActiGraph has developed both uni-axial and tri-axial accelerometers for use in research. A uni-axial accelerometer from ActiGraph, such as the GT1M model, measures accelerations in the vertical plane at a constant 30 hertz (Rothney, Apker, Song, & Chen, 2008). The tri-axial accelerometer from ActiGraph, such as the GT3X model, measures accelerations in three different planes: vertical, horizontal, and lateral planes. This model can sample data at rates of up to 100 hertz. While the data collection is important, there must also be ways to analyze the data. Much physical activity research in the 1990’s and early 2000’s was conducted without the use of software developed by manufacturers to score data. Thus, researchers developed different ways to analyze the data gleaned from accelerometers. Also, due to limitations in the memory capacity of early model ActiGraphs, the sampling rate (epoch) was set at one minute. However, with the advance of technology, researchers now have the ability to sample and store data at shorter epochs, as low as 1-second. Because the newer models of the ActiGraph have been in the field since 2010 only, there is little published research on the effects of altering the sampling rate of accelerometers in physical activity.

Prior to the development of the ActiGraph manufacturer's software to clean and score the data, Dr. Patty Freedson developed a novel method to assess how the output from the accelerometers was to be scored (Freedson et al., 1998). After each minute of measurement of the accelerometer, the raw accelerations (the movements in the vertical plane) were summed and saved as a quantity called a "count." These counts were the final data outputs from the accelerometers. Using the steady-state oxygen cost of movement at different intensities as the criterion measure, accelerometer cut-points were derived for light intensity (≤ 1951 counts per minute), moderate intensity (1952-5724 counts per minute), hard intensity (5725-9498 counts per minute), and very hard (≥ 9499 counts per minute) intensity physical activity. Using these cut-points, accelerometer data counts can now be translated into different intensities of physical activities. Numerous other cut-points have been developed for various populations, to reflect intensities of lifestyle physical activity (Hendelman, Miller, Baggett, Debold, & Freedson, 2000; Swartz et al., 2000), and to express time spent in sedentary behaviors (Matthews et al., 2008).

Because of Freedson's research, accelerometers can now be used in large-scale studies to assess physical activity patterns of countries. In the United States, a national study, the National Health and Nutrition Examination Survey (NHANES), was commissioned in 2003-2004 to study physical activity and other health outcomes in Americans. In this nationwide collection of data, over 6,000 individuals wore an accelerometer for at least 3 days to assess physical activity levels. Troiano et al. (2008) used accelerometer data from the 2003-2004 NHANES study to assess the activity levels of Americans. In order to assess moderate and vigorous intensity activity, Troiano et al.

used cut-points of 2,020 counts per minute for moderate intensity activity and 5,999 counts per minute for vigorous intensity activity. Additionally, in order to assess whether or not an individual met the recommendations of 30 minutes of moderate intensity per day, bouts of moderate intensity activity had to be at least 10 minutes in length or the activity would not count towards meeting the recommendations. When applying the cut-points and criteria, Troiano et al. reported that less than 5% of Americans met the recommendations for physical activity.

Limitations of the ActiGraph to assess sedentary behaviors. The ActiGraph is a measurement device designed to assess physical activity (Welk, McClain, Eisenmann, & Wickel, 2007). Many studies have utilized the ActiGraph to assess sedentary behavior (Healy, Wijndaele, et al., 2008; Matthews et al., 2008). However, there have been few studies that have validated the use of the ActiGraph to accurately measure sedentary behavior. Kozey-Keadle et al. (2011) showed that the ActiGraph had a low level of agreement with direct observation when using the 100 counts per minute criteria for sedentary behavior (R^2 = .39). These data show that the ActiGraph may not be a good measure of sedentary behavior as it is currently being used. While the ActiGraph measures physical activity accurately, using the current cut-points may not yield accurate results in the evaluation of sedentary behavior.

Integrated units. An emerging area in the research of physical activity assessment is the use of measurement devices that collect different types of data. The Actiheart (CamNTech, Cambridge, United Kingdom), for example, uses the heart rate response for an ECG lead and movement data from an accelerometer to predict activity energy expenditure with similar accuracy to that of indirect calorimetry (Crouter, Churilla, & Bassett, 2008). New devices, such as the Zephyr Bioharness (Zephyr Technology, Annapolis, MD, USA) also collect heart rate and activity data to measure activity level, but it has not been validated on the classification of sedentary behavior. An advantage of the integrated devices is that they may give more information about whether an individual is sitting or standing because they measure the heart rate and movement patterns.

Calorimetry. There are two types of commonly used calorimetry: direct and indirect. Direct calorimetry measures the total amount of heat produced during activity. This is achieved by having an individual stay inside a small chamber (10 x 10 feet) that keeps gases and heat contained within. The total heat exchange can be measured to provide an energy cost for a given activity. Indirect calorimetry measures the total amount of oxygen consumed during an activity rather than measuring heat. By collecting expired gases and analyzing the percent of carbon dioxide and oxygen exhaled and the volume of air exhaled, an estimation of energy expenditure can be computed. An example of an indirect calorimetry method used in field research is the Oxycon Mobile (Oxycon Mobile™, CareFusion, San Diego, CA). This device has been validated as accurately assessing the oxygen costs of physical activity (Perret & Mueller, 2006a). Because of the limitations in body movement of using a small chamber in direct calorimetry, indirect calorimetry often is utilized in measuring the energy cost of physical activities.

Assessment of Sedentary Behaviors

The assessment of sedentary behavior is an evolving field with few specific protocols developed. Although some devices have been used to measure sedentary behavior, the validity of these measures may not be sufficient to justify the use in research.

ActivPAL. The ActivPAL is a measurement device designed to assess posture. By utilizing a built-in inclinometer and wearing the device on the thigh, the ActivPAL can distinguish the difference in posture while sitting, standing, and walking. This device has been utilized in research to determine time spent in sedentary behaviors versus time spent engaged in physical activity, such as walking (Hart, McClain, & Tudor-Locke, 2011). The ActivPAL counts the number of steps taken but does not measure the intensity level of physical activity. Because of the unique ability of the ActivPAL to accurately assess posture (Davies et al., 2011), it is often used in research to assess sedentary time. However, because of the limited capacity to assess physical activity intensity, this device is not typically used in large-scale research.

Godfrey, Culhane, and Lyons (2007) examined the validity of the ActivPAL against a dual-accelerometer system (Analog Devices ADXL202). Ten participants (3 male, 7 female) wore the ActivPAL and the ADXL202 for approximately six hours of free-living activity to determine if the ActivPAL accurately measured time spent in physical activity and sedentary behaviors. After analysis, there was 98% agreement reported between the two devices in assessing time spent sitting, standing, and walking. The authors concluded that the ActivPAL had a high level of accuracy in assessing posture and activity in free-living conditions.

The ActivPAL has also been validated with direct observation measures. Grant, Ryan, Tigbe, and Granat (2006) compared the data from individuals wearing 3 ActivPAL devices with video records of 10 participants (6 male, 4 female, mean age = 43.6 years) performing a randomized series of activities of daily living. Time spent in each posture was determined through visual observation and compared with the objectively assessed time in each posture from the ActivPAL. The overall level of agreement between observer and the ActivPAL on a second-to-second basis was 95.9%. The authors concluded that the ActivPAL was a valid measure of postural assessment.

The ActivPAL has been validated to assess posture and step count. While it cannot determine the intensity of activity, it is able to assess posture, which may be more important for assessing sedentary behaviors.

Summary

The approach of the exercise and wellness community has been one of attempting to increase levels of moderate-intensity physical activity in an attempt to mitigate negative health consequences from sedentary lifestyles. However, a new wave of literature is suggesting that it may be effective to put an emphasis on the reduction of sedentary time in addition to increasing time spent in moderate-vigorous intensity physical activity.

Chapter 3

METHODS

This chapter highlights the methods used in the four separate studies that compose chapters 4-7 of this dissertation. These studies focused on the over-arching theme of the assessment of physical activity and sedentary behaviors. The four papers included in this study are on the topics of assessment of the oxygen cost of selected adult and child care activities, assessment of the oxygen cost of household cleaning activities, assessing accelerometer epoch lengths using multiple accelerometers, and the assessment of sedentary behaviors with multiple measurement devices.

Project One

The Oxygen Cost of Selected Adult and Child Care Activities. The first project described was designed to assess the energy cost of several different adult and child care activities for activities in the 2011 Compendium of Physical Activities that had not been measured. Nineteen healthy adults, ages 20-55, volunteered to complete the study. Participants were a convenience sample of Arizona State University employees, students, friends, and family that were recruited for the study via word of mouth.

Participants completed four different tasks for the study: 1) pushing an infant in a stroller, 2) pushing an adult in a wheelchair, 3) washing and dressing an infant, and 4) walking slowly and carrying an infant. To assess the oxygen cost of each activity, participants wore the Oxycon Mobile portable metabolic measurement system.

Descriptive statistics were computed using SAS 9.2 (version 9.2; SAS Institute, Cary, North Carolina). The mean oxygen uptake in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ and standard deviations of each activity were reported. The mean MET levels and standard deviations for each activity also were computed and reported.

Results from the study were presented in abstract form at the 2011 American College of Sports Medicine national meeting and accepted for publication in the International Journal of Exercise Science. Project one is presented in chapter 4.

Project Two

The Oxygen Cost of Household Cleaning Activities. The second project described was designed to assess the oxygen cost of household cleaning activities. Sixteen healthy adults, ages 18-62, volunteered for the study. Participants were a convenience sample of Arizona State University employees, students, friends, and family that were recruited for the study via word of mouth.

Participants completed three different tasks for the study: 1) mopping a floor, 2) scrubbing a bathtub, and 3) washing dishes. To assess the oxygen cost of each activity, participants wore the Oxycon Mobile portable metabolic measurement system.

Descriptive statistics were computed using SAS 9.2 (version 9.2; SAS Institute, Cary, North Carolina). The mean oxygen uptake in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ and standard deviations of each activity were reported. The mean MET levels and standard deviations for each activity also were computed and reported.

Results from the study were presented in abstract form at the 2011 Southwest American College of Sports Medicine regional meeting and will be submitted for publication in the Journal of Occupational and Environmental Medicine. Project two is presented in chapter 5.

Project Three

Assessment of Activity Levels Using Multiple Accelerometer Epochs. The third project described was designed to compare different accelerometer epoch lengths (1-, 5-, 15-, and 60-seconds) on different activity levels (light, moderate, and vigorous) and sedentary behaviors.

This study used a cross-sectional design to identify the effects of ActiGraph GT3X epoch lengths (1-, 5-, 15-, and 60 seconds) on time spent in sedentary behaviors and various intensities of physical activity. A convenience sample of 30 adults (15 men and 15 women), aged 20-36, with varied physical activity levels volunteered for the study. Each participant wore four ActiGraph GT3X accelerometers on an elastic belt with two accelerometers over each anterior superior iliac spine of the hip. Each accelerometer was randomly assigned to record different epoch lengths of 1 second, 5 seconds, 15 seconds, and 60 seconds. Participants wore the accelerometers for 7 days and performed daily activities as usual.

Data analysis was conducted using SAS 9.2 (version 9.2; SAS Institute, Cary, North Carolina). A repeated measures ANOVA was conducted to determine differences in minutes of sedentary behavior, light-, moderate-, and vigorous-intensity activity by epoch length. Tukey's HSD test was performed post-hoc to determine significant group differences.

Results from the study were presented in abstract form at the 2011 Southwest American College of Sports Medicine regional meeting and are being prepared for publication in a sports medicine journal. Project three is presented in chapter 6.

Project Four

Assessment of Sedentary Behaviors Using Multiple Measurement Devices. The fourth project described was designed to use multiple measurement devices to determine if the activities assessed were to be classified as light-intensity or sedentary behaviors. A convenience sample of 16 adults (8 men and 8 women), aged 20 - 47, with varied physical activity levels volunteered for the study. Participants were recruited by word of mouth with a goal of recruiting individuals that were both active and spent a large amount of time sedentary.

This study examined the validity of three activity monitors to assess sedentary behaviors and light-intensity PA against the Oxycon Mobile. The test-retest reliability of each device was also assessed using Pearson's correlation. Each of the 16 participants (8 male, 8 female) wore the Oxycon Mobile, ActiGraph GT3X+, ActivPAL, and SenseWear Armband. Participants performed 7 activities: walking at 1.0 mph, walking at 1.5 mph, walking at 2.0 mph, working in a kitchen, reading a book while standing, typing at a computer while seated, and playing a board game while seated.

Data were analyzed using SPSS 20 (SPSS Inc., Chicago, IL). Activities were classified as either sedentary or light-intensity for each epoch. Mean absolute percent error was calculated for each monitor compared to the Oxycon Mobile. Pearson's correlation was used to analyze test-retest reliability of the monitors from the first session to the second session.

This research was supported by the Plus One Active Research Grant on Wellness from the American College of Sports Medicine Foundation. Project four was submitted for presentation at the 2013 national ACSM meeting and will be prepared for publication in a sports medicine journal.

Chapter 4

OXYGEN COST OF PERFORMING SELECTED ADULT AND CHILD CARE ACTIVITIES

Abstract

Purpose. The purpose of this study was to assess the oxygen cost of four care-related activities in the Compendium of Physical Activities.

Design. Cross-sectional.

Methods. Nineteen participants (n = 10 women, n = 9 men; Age = 36.4 ± 13.6 yrs; % Fat = 34.1 ± 10.5; BMI = 28.1 ± 4.5 kg/m^2) performed four activities: 1) pushing an infant in a stroller, 2) pushing an adult in a wheelchair, 3) carrying an infant, and 4) bathing and dressing an infant. The oxygen cost was assessed using a portable metabolic unit. Activities were performed in random order for 8 minutes.

Results. The oxygen cost and heart rates, respectively, for healthy adults during care related activities were 3.09 METs and 90 ± 8 beats per minute (bpm) for pushing an infant in a stroller, 3.69 METs and 97 ± 9 bpm for pushing an adult in a wheelchair, 2.37 METs and 85 ± 9 bpm for carrying an infant, and 2.00 METs and 87 ± 9 bpm for bathing and dressing an infant.

Conclusions. Carrying an infant and bathing an infant are light-intensity physical activities and pushing a wheelchair or a stroller are moderate intensity activities. The latter activities are of sufficient intensity to meet health-related physical activity

recommendations.

Introduction

Regular physical activity is a health enhancing behavior and is recommended for weight management and to reduce the risks for several chronic diseases, disabilities, and premature mortality (DHHS, 2008). The 2008 U.S. Physical Activity Guidelines recommend all adults perform 150 minutes of moderate intensity activity (or 75 minutes of vigorous, or an equivalent combination) per week (DHHS, 2008). However, many adults perceive time limitations as a barrier for performing leisure-time activities at this level. Thus, it is important to identify the intensity of activities of daily living that adults commonly perform which may have health-promoting benefits. Both men and women take care of others, however, women often bear much of the responsibility of caring for children (DeMaris, Mahoney, & Pargament, 2011) and older adults (Chesley & Poppie, 2009) and these responsibilities can be time consuming.

Using data from the 2003-2008 American Time Use Survey (ATUS), Tudor-Locke et al. (Tudor-Locke et al., 2010a) showed that 16.5% of adults reported taking care of children in a usual day. The ATUS data from 2005-09 (BLS, 2010) showed that women spent nearly 6.7 hours per day with children under 6 years of age, of which nearly 1.1 hours were spent providing physical care activities, such as bathing, dressing, and feeding young children. Another 0.9 hours were spent performing other types of child care activities, such as: playing sports, hobbies, transporting children, and reading and talking with children (CDC, 2008). Little is known about the energy cost of these activities. Given that women tend to report lower levels of leisure time physical activity compared to men, it is plausible that infant care tasks may represent an unexamined aspect of their physical activity profiles.

The Compendium of Physical Activities (Compendium) provides a source to identify the oxygen cost of many activities performed on a daily basis, including caring for others. First published in 1993 (Ainsworth et al., 1993) and revised in 2000

(Ainsworth et al., 2000), the Compendium includes both measured and estimated MET values. A MET is a unit of movement intensity that reflects an activity metabolic rate divided by a resting metabolic rate. Recently, a second revision to the Compendium was completed to create the 2011 Compendium. The goal of the 2011 Compendium (Ainsworth et al., 2011) was to update the activities listed and to identify MET values from published studies for as many activities as possible, and to provide citations for these activities.

Few studies have measured the oxygen costs of caring for infants. In a study with mothers of young children less than 5 years old, Brown et al. (Brown, Ringuet, Trost, & Jenkins, 2001) measured walking with a stroller as 3.8 METs. De Guzman et al. (de Guzman et al., n.d.) measured the oxygen cost of bathing children while standing as 3.48 METs. Both of these reports indicate these activities are sufficient to meet national physical activity recommendations if performed for sufficient duration. Child care activities with infants may require less intensity than those with older children. De Guzman et al. (de Guzman et al., n.d.) reported standing and holding a child as 1.92 METs. Rao et al. (Rao, Gokhale, & Kanade, 2008) reported breast feeding an infant while sitting or reclining as 2.0 METs. Other studies collectively identify infant care activities at 2.0 METs (Bassett & Ainsworth, 2000; Moy, Scragg, McLean, & Carr, 2006; Torun, McGuire, & Mendoza, 1982) which are considered to be light-intensity (1.6 to 2.9 METs) (Pate, O'Neill, & Lobelo, 2008). A review of the 2011 Compendium shows several child care activities for which the oxygen cost has yet to be measured. These included dressing, grooming, feeding, and occasional lifting of infants while sitting or kneeling; reclining with a baby; and walking slowly while holding an infant weighing less than 15 lbs.

With the growing aging population, adults are more likely to care for aging parents or adults with disabilities, some of whom will require assistance with the activities of daily living and rely on wheelchairs for transportation (Hartman, Catlin, Lassman, Cylus, & Heffler, 2008; Simonazzi, 2009). Such activities may include feeding, dressing, personal grooming, assisting one into and out of a wheelchair, and pushing a wheelchair. Little is known about the oxygen cost of such activities. Pushing a wheelchair has dual purposes as a household care task and an occupational task in nursing, physiotherapy, and other care-oriented professions. Pushing a wheelchair with adequate speed may be of sufficient intensity to reduce one's risks for chronic conditions while still caring for dependent adults.

The purpose of this study was to measure the oxygen cost for care related activities listed in the Compendium that currently has only estimated MET values for these activities. We performed a laboratory study to measure the oxygen cost of four child and adult care activities: 1) pushing an infant in a stroller, 2) pushing an adult in a wheelchair, 3) walking slowly and carrying an infant, and 4) bathing and dressing an infant.

Methods

Nineteen healthy adults (n = 10 women, n = 9 men; (mean ± sd) age = 36.4 ± 13.6 y; % Fat = 34.1 ± 10.5 %; body mass index = 28.1 ± 4.5 $kg \cdot m^{-2}$) volunteered for the study. All study participants read and signed an informed consent form approved by the Arizona State University (ASU) Institutional Review Board prior to study participation. Upon completion of the tests, participants received monetary compensation for their time.

A cross-sectional study design was used with a single 1.5 hour visit to the Healthy Lifestyles Research Center at ASU between July and October 2010. At the beginning of the visit, participants had their weight in kilograms and body composition measured using a Tanita bioelectrical-impedance scale (TBF-300, Arlington Heights, IL). Height was measured in cm using a wall mounted measuring tape. Following this a heart rate monitor (Polar, WearLink, Kempele, Finland) was placed and their heart rate was recorded in beats/min (bpm). The oxygen cost in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ of the care related activities was assessed at rest and during each activity by measuring the oxygen uptake (VO_2). Pulmonary gas exchange and ventilation were measured breath by breath using a portable metabolic unit to compute their VO_2 (Oxycon Mobile™, CareFusion, San Diego, CA) (Perret & Mueller, 2006). The metabolic unit was fixed to the back of the participant via a chest harness. A flexible face mask covered the participant's mouth and nose. Care was taken to ensure that an adequate seal was achieved. The metabolic unit was calibrated using manufacturer's specifications prior to each trial.

Prior to the start of the tests, participants rested in a chair for 10 minutes to obtain resting heart rate and VO_2 values. Each test was performed for eight continuous minutes with four minutes of rest in a seated position between each activity.

Mannequins were used as test subjects to provide consistency in the test environment for each participant. An adult mannequin (height: 166 cm and weight: 75 kg) was used as the subject for the pushing a wheelchair task. The weight of 75 kg for the adult in the wheelchair was chosen using NHANES 2003-2006 data showing the mean heights and weights of males and females at varying ages (McDowell, Fryar, Ogden, & Flegal, 2008). The mean weight was 75 kg for males and females ages 20-39 (McDowell, Fryar, Ogden, & Flegal, 2008). There were no data available for wheelchair bound adults. An infant mannequin that was an equivalent size to a 2 month old child (length: 38 cm and weight: 5 kg, with added weights), was used for pushing a stroller, bathing and dressing an infant, and walking and carrying an infant.

The care related activities were assigned to participants in a random order to reduce the chance of systematic bias resulting from activities being performed in the same order. Details for each task are described. [1] *Pushing an infant in a stroller*: The stroller (Eddie Bauer Travel System Stroller) contained a baby mannequin that was pushed indoors on a flat firm (concrete) surface in a set, rectangular, 67 meter course.

Participants walked and pushed the stroller at a comfortable pace and were timed at lap intervals and instructed to speed up, slow down, or maintain the current pace by study personnel to ensure a constant speed was maintained for 8 minutes. The average speed for pushing the stroller was 1.12 $m \cdot sec^{-1}$ (4.0 $km \cdot h^{-1}$). [2] *Pushing an adult in a wheelchair*: A standard hospital wheelchair (Invacare, Eylria, OH) containing an adult mannequin was pushed indoors on a flat firm (concrete) surface in a set, rectangular, 67 meter course. The mannequin was secured into the wheelchair at the chest and legs for stability. Participants walked and pushed the wheelchair at a comfortable pace and were guided by study personnel to ensure the pace remained constant for 8 minutes. The average speed for pushing the wheelchair was 1.12 $m \cdot sec^{-1}$ (4.0 $km \cdot h^{-1}$) [3] *Washing and dressing an infant*: A simulated baby washing protocol was used to wash and dress the infant mannequin in a diaper and clothing. Participants were supplied with a towel, soap/shampoo bottle, washcloth, and cup to simulate washing activities. Participant kneeled or sat to undress the mannequin, placed it in a tub (without water), simulated washing the infant, removed the infant from the tub, dried it with a towel, and then dressed the infant with a diaper and clothes. [4] *Walking slowly and carrying an infant*: This activity was performed in a large room where the participants walked slowly and moved freely at their own speed while carrying the infant mannequin. Each participant was allowed to carry the infant in a preferred position. The walking speed during this task was not measured.

Data were analyzed using means and standard deviations to assess the VO_2 in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ and the heart rate in bpm at rest and during each task. Data were averaged over a 15 second period while using minutes 3-7 for data analysis. The MET value for each activity was computed by dividing the VO_2 in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ for each task by 3.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ (Balke, 1960). SAS 9.2 (SAS, Cary, NC) was used for data analysis. A one-way ANOVA was used to test differences by gender in each task.

Results

All participants completed each activity in their assigned sequence. Table 1 provides descriptive data on the age, weight, height, and percentage body fat for men, women, and all participants combined.

Table 1.

Descriptive Statistics of Study Participants Means (SD)

	Total (n = 19)	Women (n = 10)	Men (n = 9)
Age (years)	38.2 (13.4)	38.8 (13.5)	37.6 (14.1)
Weight (kg)	86.8 (17.7)	76.8 (15.6)	97.9 (13.0)
Height (cm)	172.0 (9.9)	167.2 (5.7)	177.4 (11.1)
Body Fat (%)	32.1 (10.2)	37.9 (10.1)	25.5 (5.3)

Table 2 presents the steady-state heart rate in bpm during each activity for men, women, and all participants combined for each task. The resting heart rate prior to the start of the tasks was 67 ± 8 bpm (men: 66 ± 8 bpm; women: 68 ± 8 bpm). No significant differences were observed between men and women for heart rate at rest or during the activity.

Table 2.

Steady-state Heart Rates by Task in Beats per Minute (Mean ± SD)

Task	Total (n = 19)	Women (n = 10)	Men (n = 9)
Pushing Stroller	90 ± 8	91 ± 9	89 ± 6
Pushing Wheelchair	97 ± 10	100 ± 11	94 ± 7
Carrying Infant	85 ± 9	86 ± 10	83 ± 9
Bathing Infant	88 ± 11	88 ± 13	87 ± 9

Table 3 presents the VO_2 in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ and the associated MET values for men, women, and all participants combined for each task. The resting VO_2 was 3.7 ± 0.7 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ (men, 3.9 ± 0.8 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$; women, 3.5 ± 0.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$). The slightly elevated resting VO_2 may have been the result of previous activity performed during the day and time of day of the testing. The VO_2 and associated MET values were similar for men and women on all activities except pushing a wheel chair, which was higher for women than for men ($p < 0.05$).

Table 3.

Oxygen Uptake and Associated METs of Care Activities

Task	Total (n = 19)	Women (n = 10)	Men (n = 9)
Pushing Stroller	10.8 ± 2.4 (3.1 ± 0.7)	10.9 ± 2.5 (3.1 ± 0.7)	10.6 ± 2.3 (3.0 ± 0.7)
Push a Wheelchair	12.9 ± 2.8 (3.7 ± 0.8)	13.9 ± 2.5 * (4.0 ± 0.7)	11.7 ± 2.8 (3.3 ± 0.8)
Carrying Infant	8.3 ± 1.9 (2.4 ± 0.5)	8.7 ± 1.9 (2.5 ± 0.5)	7.9 ± 1.9 (2.3 ± 0.5)
Bathing Infant	7.0 ± 2.3 (2.0 ± 0.7)	7.1 ± 2.6 (2.0 ± 0.7)	6.9 ± 2.0 (2.0 ± 0.6)

Data are presented as mean oxygen uptake and standard deviation in ml.kg-1.min-1 with associated METs in parentheses

* $p < 0.05$

Discussion

This study measured the energy cost of the commonly performed care activities of pushing a stroller and a wheelchair, carrying an infant, and bathing and dressing an infant. All activities were in the light-to-moderate intensity range. Pushing a 75 kg adult sized mannequin in a wheelchair and pushing a 5 kg mannequin infant in a stroller at 4.0 $km \cdot h^{-1}$ were deemed moderate intensity activities at 3.7 and 3.1 METs, respectively. Carrying and bathing and dressing the infant mannequin were light intensity activities at 2.4 and 2.0 METs, respectively.

Knowing the MET values of these care activities allows for correct classification of time spent at varying intensities and can provide a resource of suitable activities that meet U.S. Physical Activity Guidelines. While carrying and bathing an infant are classified as light-intensity activities, their MET intensities of 2.4 and 2.0, respectively, double the caloric energy expenditure over rest. This may be beneficial in preventing inactivity-related conditions (Healy et al., 2007) and has broad implications for energy balance since 16.5% of adults reported doing physical care activities for household children in the 2003-2008 American Time Use Surveys (Tudor-Locke et al., 2010). As well, pushing a stroller and a wheelchair, reported as 3.09 and 3.69 METs respectively, increase the resting metabolism nearly threefold. Just 15 minutes a day of these activities may lower all-cause mortality by 14% (Wen et al., 2011). This is positive news for individuals that spend a significant amount of time pushing strollers and wheelchairs, such as parents of young children, and adults who care for elderly adults, as they may be more likely to meet the physical activity guidelines because of the time spent engaging in such activities.

There are several child and infant care activities listed in the Compendium including: standing and holding an infant; walking and carrying a small child or infant; bathing, dressing, and feeding an infant; pushing an infant or small child in a stroller; playing with small children; and other general child care activities. Published MET values for playing with children range from 2.2 to 5.8 METs. Moy (2006) reported sitting and playing with children as 2.2 METs. Bassett and Ainsworth (2000) reported walking and running while playing with children as 3.8 METs. Fischer et al. (Fischer, Watts, Jensen, & Nelson, 2004) reported playing tag and soccer with children aged 5 to 12 years old as 5.8 METs. These latter activities are in the moderate intensity category of 3.0 to 5.9 METs (DHHS, 2008).

Three of the care activities measured in this study had estimated MET values in the 2000 Compendium of Physical Activities (Ainsworth et al., 2000). One motivation for measuring the oxygen cost of these care activities was to have measured MET values in the 2011 Compendium (Ainsworth et al., 2011). Interestingly, the 2000 Compendium estimated MET values were similar to the measured values for bathing an infant

(Compendium code 05185; estimated 2.5 METs vs. measured 2.0 METs) and for pushing a wheelchair (Compendium code 17105; estimated 4.0 METs vs. measured 3.69 METs). The 2000 Compendium estimated MET value was lower for pushing a stroller (Compendium code 17100; estimated 2.5 METs vs. measured 3.09 METs). Carrying an infant (Compendium code 05183) was a new activity added to the 2011 Compendium with a measured value of 2.37 METs.

It should be noted that the MET values published in the 2011 Compendium may differ from those published in this study. For ease of presentation, the Compendium MET values are rounded to significant digits of 0, 3, 5, and 8. Also, the 2011 Compendium MET values reflect the mean METs of studies that have published measured MET values for similar activities. For example, in 2001, Brown et al. measured the VO_2 of women pushing a stroller at 5.0 $km.h^{-1}$ reported as 4.9 METs (Brown et al., 2001). This MET value is higher than the value measured in this study (3.09 METs) and may be due to participants pushing the stroller at a faster pace than the pace used in the current study (4.0 $km \cdot h^{-1}$). Also, the Brown et al. (2001) study included only women who pushed their own children who were on average 2.3 years old and weighed more than the 5 kg infant mannequin used in the current study. Because the 2011 Compendium averages MET values across the different studies published, averaging the Brown et al. study (4.9 METs) and the current study (3.09 METs) resulted in a 2011 Compendium MET value for pushing a stroller of 4.0 METs.

The U.S. Physical Activity Guidelines recommend adults engage in 150 minutes of moderate-intensity activity per week ranging from 3.0-5.9 METs, or 75 minutes of vigorous-intensity activity per week, ≥ 6.0 METs (DHHS, 2008). As noted earlier, pushing a child in a stroller and pushing adults in a wheelchair are moderate intensity activities that can contribute to meeting the Physical Activity Guidelines. By classifying these activities as moderate intensity, more individuals may meet the Physical Activity

Guidelines. It is important for activity intensity to be properly classified to assess individual and national activity levels.

One limitation for this study was that participants were required to walk at a 4.0 $km \cdot h^{-1}$ pace for pushing the wheelchair and the stroller and were guided by study personnel to maintain that speed. Participants had a tendency to increase speed throughout the duration of the activities, and were timed at lap intervals and instructed to speed up, slow down, or maintain the current pace by study personnel to ensure a constant speed was maintained for the activity duration. This may have limited the speed at which participants performed the activity and altered the VO_2 of the pushing activities. Another limitation related to the pushing activities was the amount of friction generated by the stroller and wheelchair. A low rolling resistance may have not have made a significant contribution to the oxygen cost of these activities. Additionally, participants with infant children who engaged in the activities measured in this study may have been more familiar with the activities and exhibited a movement economy that could have lowered their VO_2 in selected activities. The simulated washing of a mannequin, rather than washing an infant, may also have resulted in a change in the energy cost of this activity. Holding a live infant and pouring water may affect the oxygen cost of this activity.

Conclusion

The oxygen cost of four care-related activities was measured to show that pushing a wheelchair and a stroller are classified as moderate-intensity activities and carrying and dressing an infant are classified as light-intensity activities. Knowing the MET values for these care activities provides useful information that may help better quantify physical activity in mothers with small children and care givers for wheelchair bound persons. We also reported measured MET values for the 2011 Compendium of

Physical Activities that replaced previously estimated values from the 2000 Compendium of Physical Activities.

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Chapter 5

OXYGEN COST OF HOUSEHOLD CLEANING ACTIVITIES

Abstract

Purpose. The purpose of this study was to assess the oxygen cost of three household cleaning activities that appear in the 2011 Compendium of Physical Activities.

Design. Cross-sectional.

Methods. Sixteen healthy participants (n = 8 women, n = 8 men; age = 36.6 ± 11.7 yrs; body mass index = 28.4 ± 4.5 $kg \cdot m^{-2}$) performed three activities: 1) mopping a floor, 2) cleaning a bathtub, and 3) clearing a table and washing dishes. The oxygen cost was assessed using a portable metabolic unit. Activities were performed in random order for 8 minutes with a 4 minute rest period between activities.

Results. The oxygen cost and heart rates, respectively, during household cleaning activities were 3.14 ± 0.91 METs and 105 ± 20 beats per minute (bpm) for mopping a floor, 2.89 ± 0.57 METs and 98 ± 15 bpm for cleaning a bathtub, and 1.93 ± 0.46 METs and 89 ± 16 bpm for clearing a table and washing dishes. There were no significant differences in heart rate or METs by gender for the activities.

Conclusions. Cleaning a bathtub and washing dishes are light-intensity physical activities and mopping a floor is a moderate intensity activity. Mopping a floor is of sufficient intensity to meet health-related physical activity recommendations.

Introduction

Regular physical activity is a health enhancing behavior that is recommended for weight management and the reduction of risks for several chronic diseases, disabilities, and premature mortality (DHHS, 2008). The 2008 U.S. Physical Activity Guidelines recommend all adults perform 150 minutes of moderate intensity activity (or 75 minutes of vigorous, or an equivalent combination) per week (DHHS, 2008). However, many adults perceive time limitations as a barrier for performing leisure-time activities at this level. Thus, it is important to identify the intensity of activities of daily living that adults commonly perform which may have health-promoting benefits. Adults perform activities in various domains during a usual day including occupation, sedentary and active leisure, transport, self-care, and household cleaning activities.

Using data from the 2003-2008 American Time Use Survey (ATUS), Tudor-Locke et al (Tudor-Locke, Johnson, & Katzmarzyk, 2010) showed that 51% of adults reported engaging in home cleaning tasks. Both men and women engage in cleaning activities, however, 65% of women reported engaging in household cleaning activities, while only 35% of men reported engaging in such activities (Tudor-Locke et al., 2010b). The ATUS data from 2010 showed that women spent nearly 1.8 hours per day engaging in housework related activities such as: scrubbing bathrooms, cleaning floors, and other assorted cleaning tasks. Another 1.2 hours were spent preparing meals and cleaning up after the meal preparation, which includes cooking different foods, setting the table, and washing the dishes. Little is known about the energy cost of these activities. Given that women tend to report lower levels of leisure time physical activity compared to men, it is plausible that housework related activities may represent an unexamined aspect of their physical activity profiles.

The Compendium of Physical Activities (Compendium) provides a source to identify the oxygen cost of many activities performed on a daily basis, including housework cleaning related activities. First published in 1993 (Ainsworth et al., 1993) and revised in 2000 (Ainsworth et al., 2000), the Compendium includes both measured and estimated MET values. A MET is a unit of movement intensity that reflects an activity metabolic rate divided by a resting metabolic rate. Recently, an additional revision to the Compendium was completed to create the 2011 Compendium (Ainsworth et al., 2011). The goal of the 2011 Compendium was to update the activities listed with evidence from published studies to identify MET values for as many activities as possible, and to provide citations for these activities.

There are many different housework cleaning activities listed in the Compendium including: sweeping floors, mopping floors, house cleaning, vacuuming, food preparation, and ironing among many others. Published MET values for vacuuming range from 2.3 to 3.8 METs (Norman, Kautz, Wengler, & Lyden, 2003; Wilke et al., 1995). Sweeping floors was assigned a MET value of 3.3 in the 2011 Compendium update (Ainsworth et al., 2011) while Kozey et al. (Kozey, Lyden, Howe, Staudenmayer, & Freedson, 2010) identified mopping a floor as 3.5 METs. These latter activities are in the moderate intensity category of 3.0 to 5.9 METs (DHHS, 2008).

A review of the 2011 Compendium shows several household cleaning activities for which the oxygen cost has yet to be measured. These included clearing a table, washing the dishes, setting a table, and cleaning a bath tub. Clearing tables, washing dishes, setting tables, and mopping floors with adequate speed may be of sufficient intensity to reduce one's risks for chronic conditions while still performing daily work or home activities.

The purpose of this study was to measure the oxygen cost for household cleaning activities listed in the Compendium that currently have only estimated or wide variation in MET values for those activities. We performed a laboratory study to measure the oxygen cost of three household cleaning activities; 1) mopping a floor using a traditional wet mop, 2) cleaning a shower using a scrub brush, and 3) clearing a table, washing the dishes, and setting a table.

Methods

Sixteen healthy adults (n = 8 women, n = 8 men; age = 36.6 ± 11.7 yrs; body mass index = 28.4 ± 4.5 $kg \cdot m^{-2}$) were recruited via word of mouth and volunteered for the study. All study participants read and signed an informed consent form approved by the Arizona State University (ASU) Institutional Review Board prior to study participation. Upon completion of the tests, participants received $50 compensation for their participation.

A cross-sectional study design was used with a single 1.5 hour visit to the exercise physiology laboratory at ASU during June and July 2011. At the beginning of the visit, participants had their weight in kilograms measured using a Tanita bioelectrical-impedance scale (TBF-300, Arlington Heights, IL). Height in centimeters was measured using a wall-mounted stadiometer (Seca, Germany). Next, a heart rate monitor (Polar, WearLink, Kempele, Finland) was placed around the participants' chest and their heart rate was recorded in beats/min (bpm). The oxygen cost in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ of the household cleaning activities was assessed at rest and during each activity by measuring the oxygen uptake (VO_2). Pulmonary gas exchange and ventilation were measured breath by breath using a portable metabolic unit to compute their VO_2 (Oxycon Mobile™, CareFusion, San Diego, CA)(Perret & Mueller, 2006b). The metabolic unit was fixed to the back of the participant via a harness. A flexible face mask covered the participant's mouth and nose. Care was taken to ensure that an adequate seal was achieved. The metabolic unit was calibrated using manufacturer's specifications prior to each trial.

Prior to the start of the tests, participants rested in a chair for 10 minutes to obtain resting heart rate and VO_2 values. Each test was performed for eight continuous minutes with four minutes of rest in a seated position between each activity. Activities were performed in a randomly selected order for a minimum of 8 minutes or until the participant deemed the selected surface clean.

For the wet mop activity, a pre-mixed dirt solution was applied to the laminate flooring. Participants were instructed to mop the 10 x 10 foot floor using a standard mop until they deemed it clean. In the shower cleaning task, a standard tub and shower unit was used for cleaning. A pre-mixed solution simulating soap and other debris was used to dirty the shower before each cleaning. Participants used a water spray hose, cleaning solution, and scrub brush to clean the shower unit he or she deemed it clean. The dish clearing, washing, and table setting task utilized a 4 person table setting with each setting containing a plate, mug, cup, fork, spoon, and knife. Participants were instructed to clear the table, simulate washing and drying each item, and re-set the table when the items had been cleaned.

The household cleaning activities were assigned to participants in a random order to reduce the chance of systematic bias resulting from activities being performed in the same order. Details for each task are described. (1) *Mopping a floor with a standard wet mop*: The mop was a 9.5 inch sponge mop (Libmon 00104, Arcola, IL). Participants filled a bucket with water and a cleaning solution to mop the floor. When cleaning the floor, participants were instructed to clean the floor in the manner and at the pace they normally would perform the task. After completing the task, the floor was sanitized for the next use. (2) *Cleaning a shower/tub*: A standard shower and tub unit was used for this cleaning task. Individuals cleaned the shower using the provided hose, cleaning solution, and scrub brush. Participants were instructed to clean the tub in the manner and at the pace they typically performed the task. After completion of the cleaning, the tub was sanitized for the next use. (3) *Clearing the table, washing the dishes, and setting the table*: Participants cleared the table using only their hands, carried the dishes to a wash basin 10 feet away, and proceeded to simulate washing the dishes in the basin using a dish towel. Participants then proceeded to simulate drying the dishes. After the washing and drying had been completed, participants then re-set the table using the same dishes.

Data were analyzed using means and standard deviations to assess the VO_2 in $ml^{-1}.kg^{-1}.min^{-1}$ and the heart rate in bpm at rest and during each task. Data were averaged over a 15 second period for data analysis. The first two minutes of each activity were dropped and the last minute of each activity was dropped. The MET value for each activity was computed by dividing the VO_2 in $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ for each task by 3.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ (Balke, 1960). SAS 9.2 (SAS, Cary, NC) was used for data analysis. A one-way ANOVA was used to determine differences between men and women for each household cleaning activity. The alpha level was set at 0.05 for all tests.

Results

All participants completed each activity in their assigned sequence. Table 4 shows the age, weight, and height for men, women, and all participants combined. Men and women were similar in age, while men were taller and heavier than the women.

Table 4.

Means (SD) for Descriptive Statistics of Study Participants

	Total (n=16)	Women (n=8)	Men (n=8)
Age (years)	36.6 (13.4)	36.5 (12.4)	36.6 (15.3)
Weight (kg)	82.6 (22.5)	71.7 (17.7)	93.5 (22.3)
Height (cm)	170.0 (11.7)	161.6 (4.1)	178.4 (10.8)

Table 5 presents the steady-state heart rate in bpm during each activity for minutes 2-7 of each activity for men, women, and all participants combined for each task. The resting heart rate prior to the start of the tasks was 74 ± 12 bpm (men, 68 ± 9 bpm; women, 81 ± 12 bpm). There were no significant differences in steady state heart rate for each task (mopping the floor: $p = 0.11$, cleaning the tub: $p = 0.08$, and washing dishes: $p = 0.12$).

Table 5

Means (SD) for Heart Rate (bpm) for Household Cleaning Activities

Task	Total (n=16)	Women (n=8)	Men (n=8)
Mopping Floor	105 (20)	113 (13)	97 (23)
Cleaning Tub	98 (15)	105 (13)	92 (15)
Washing Dishes	89 (16)	96 (12)	83 (19)

Table 6 presents the VO_2 in $ml^{-1}.kg^{-1}.min^{-1}$ and the associated MET values for men, women, and all participants combined for each task. The resting VO_2 was 4.9 ± 1.5 $ml^{-1}\cdot kg^{-1}\cdot min^{-1}$ (men, 4.7 ± 1.2 $ml^{-1}\cdot kg^{-1}\cdot min^{-1}$; women, 5.0 ± 1.8 $ml^{-1}\cdot kg^{-1}\cdot min^{-1}$). The VO_2 and associated MET values were similar for men and women on all activities. There were no significant differences between men and women for mopping the floor ($p = 0.85$), cleaning the tub ($p = 0.80$), or washing dishes ($p = 0.95$).

Table 6

Means ± SD for the Oxygen Cost of Household Cleaning Activities in VO_2 and METs (in parentheses)

Task	Total (n=16)	Women (n=8)	Men (n=8)
Mopping Floor			
	11.0 ± 3.2	11.1 ± 1.8	10.8 ± 4.3
	(3.14 ± .91)	(3.18 ± .51)	(3.09 ± 1.23)
Cleaning Tub			
	10.1 ± 2.0	10.1 ± 1.3	10.1 ± 2.6
	(2.85 ± .57)	(2.88 ± .37)	(2.90 ± .74)
Washing Dishes			
	6.8 ± 1.6	6.7 ± 1.1	6.9 ± 2.0
	(1.93 ± .46)	(1.90 ± .31)	(1.96 ± .57)

Discussion

This study measured the energy cost of the commonly performed household cleaning activities of mopping a floor, cleaning a bathtub, and washing dishes. All activities were in the light-to-moderate intensity range. Mopping a floor was deemed a moderate intensity activity at 3.14 METs. Cleaning a bathtub and washing dishes were classified as light intensity activities at 2.85 and 1.93 METs, respectively.

Knowing the MET values of these household cleaning activities allows for correct classification of time spent at varying intensities and can provide a resource of suitable activities that meet U.S. physical activity guidelines (DHHS, 2008). While washing dishes and cleaning a bathtub are classified as light-intensity activities, their

MET intensities of 1.93 and 2.85, respectively, double and nearly triple the caloric energy expenditure over rest. This may be beneficial in preventing inactivity-related metabolic conditions such as high blood pressure and high fasting glucose (Healy et al., 2007b) and has broad implications for energy balance since 51% of adults reported doing household cleaning activities in the 2003-2008 American Time Use Surveys (Tudor-Locke et al., 2010b). As well, mopping a floor, identified as 3.14 METs, increases the resting metabolism more than threefold which can be beneficial for maintaining cardiorespiratory fitness and reducing risks for several chronic diseases. This may be beneficial for individuals that spend a significant amount of time mopping floors, such as janitorial staff and restaurant employees, as they may be more likely to meet the physical activity guidelines because of the time spent engaging in such activities.

In the 2011 Compendium, scrubbing a bathtub was combined with several other activities, which may not have been an accurate reflection of the actual oxygen cost of scrubbing a bathtub. One motivation for measuring the oxygen cost of these household cleaning activities was to increase the precision of MET values in the 2011 Compendium. Values listed in the 2000 Compendium for cleaning a bath tub (Compendium code 05130) had an estimated MET value of 3.5 METs. This is an overestimate of the current measurement of 2.89 METs. Similarly, for clearing a table and washing dishes (Compendium code 05042), the 2000 Compendium estimated this activity at 2.5 METs. This is an overestimate of the current measurement of 1.93 METs identified in this study. Thus, compared to the values from the 2000 Compendium of Physical Activities, the energy cost of dishes and cleaning a tub were in excess of measured values. While other studies have measured the energy cost of mopping a floor (Compendium code 17100) (Kozey et al.), we determined the MET level as 3.14 METs, slightly less than the average value published in the 2011 Compendium. The results from this study might be lower than the 2000 Compendium values because there was no furniture to move on the floor and participants had a lightweight, plastic sponge mop to use for the mopping.

One limitation for this study was that some participants were professional cleaners and had a high level of familiarity with the tasks while other participants had never mopped a floor. For example, those with a higher level of familiarity with mopping a floor had a higher standard of cleanliness and thus spent more time mopping the floor with a lower VO_2 cost than those with less experience and lower cleanliness standards.

Conclusion

The oxygen cost of three household cleaning activities were measured to identify that mopping a floor is classified as a moderate-intensity activity and cleaning a tub and washing dishes are classified as light-intensity activities. Knowing the MET values for these household cleaning activities provides useful information that may help better quantify physical activity in cleaning-oriented occupations.

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Chapter 6

ASSESSMENT OF ACTIVITY PATTERNS USING MULTIPLE ACCELEROMETER EPOCHS

Abstract

Purpose. To examine differences in the time in sedentary behaviors and in physical activity (PA) using four different accelerometer epoch lengths.

Methods. 29 adults (15 males, 14 females) wore four ActiGraph GT3X accelerometers on an elastic belt with two accelerometers over each anterior superior iliac spine of the hip. Each accelerometer was randomly assigned to record at different epoch lengths (1-sec 5-sec, 15-sec, and 60-sec) for seven days to assess average weekly time spent in sedentary behaviors and in light-, moderate-, and vigorous-intensity PA levels. The 60-sec epoch cut-points for sedentary and PA intensities were divided by 60 (for 1-sec), 12 (for 5-sec), and 4 (for 15-sec) to develop comparable epoch lengths. A repeated measure ANOVA was used to assess differences in time by epoch and intensity level.

Results. Significant differences were found in the weekly minutes spent in the sedentary ($p<.0001$) and light-intensity ($p<.0001$) categories. The 1-sec epoch length was significantly different from the other epoch lengths in both the sedentary and light-intensity categories ($p<.001$).

Conclusion. Altering the epoch length resulted in differences of up to 148 min per day in sedentary behaviors and light-intensity activity between the 1- and 60-sec epochs. Selection of epoch length should be taken into account when assessing sedentary behaviors.

Introduction

There are numerous health benefits associated with increased levels of physical activity (PA), such as, decreased risks for type 2 diabetes (Laaksonen et al., 2005) and other chronic diseases and decreased relative risks of premature mortality (Katzmarzyk et al., 2009). Accordingly, the U.S. Department of Health and Human Services had issued guidelines to obtain sufficient intensity and amount of PA necessary to achieve health benefits (DHHS, 2008). To assess if individuals are meeting these guidelines, it is important to use accurate and sensitive assessment methods to measure PA.

Comparison of national health surveys has shown differences in PA levels between self-report survey and accelerometer assessment methods (Ham & Ainsworth, 2010). Ham and Ainsworth (2010) showed differences in PA patterns by race and ethnicity based on the method for PA assessment. Using the 2003-2004 NHANES accelerometer data with cut-points determined for the national data analyses, Troiano (Troiano et al., 2008) showed that fewer than 5% of U.S. adults met recommended levels for 8-10 min bouts of moderate-intensity PA. Additionally, in an analysis of the same data, Matthews (Matthews et al., 2008) showed that U.S. adults spent 55% of their days engaged in sedentary behaviors. This latter finding is important because Healy et al. (2008) have shown that time spent in sedentary behaviors is associated with increased metabolic risk factors for type 2 diabetes (Healy, Dunstan, et al., 2008).

There is considerable interest among exercise scientists and epidemiologists in the use of accelerometers to assess PA due to added precision of an objective measurement device and the elimination of biases observed with survey methods used to assess PA (Skatrud-Mickelson, Benson, Hannon, & Askew, 2011). The ActiGraph (Pensacola, Florida, USA) accelerometer models have been used frequently to assess PA in surveillance studies (Hagströmer et al., 2007; Matthews et al., 2008; Troiano et al., 2008), cross-sectional PA questionnaire validation studies (Hong, Trang, van der Ploeg, Hardy, & Dibley, 2012; Hurtig-Wennlöf, Hagströmer, & Olsson, 2010), and PA intervention research (Duncan et al., 2012; Gortmaker et al., 2012; Kozey-Keadle, Libertine, Staudenmayer, & Freedson, 2012). The earliest model of the ActiGraph (model 7164) required the number of counts representing movement intensities to be integrated over 60 sec (referred to as the epoch duration) due to limitations in the device's memory to store data collected over time periods greater than seven days. A second generation ActiGraph model (GT1M), included great memory to allow storage of movement data up to 14 days (Kozey, Staudenmayer, Troiano, & Freedson, 2010). However, the device was still limited to using a 60-sec epoch for the extended wear time. Due to continued advances in technology, recent generations of the ActiGraph (GT3X and GT3X+) now permit movement data to be integrated in epochs as short as 1-sec and stored for periods over seven days. This allows for greater precision to estimate the time spent in varying intensities, previously impossible using an epoch length that integrated movement data over one minute. Further, the added memory capacity allows researchers to study sedentary behaviors or short bursts of PA that may change within a few seconds. Short behavior patterns are seen in children (McClain, Abraham, Brusseau, & Tudor-Locke, 2008; Nilsson, Ekelund, Yngve, & Sjöström, 2002) and can have positive effects on health promotion and disease prevention (Healy et al., 2011).

Few studies have compared the use of accelerometer epoch recording times shorter than 60 sec on time spent in varying intensities of daily PA. Two studies designed to determine alternative epoch lengths in assessment of PA had participants wear one accelerometer with an epoch length of 5- or 10 sec and reintegrated those data into different epoch lengths of 15-, 30-, and 60 sec (McClain et al., 2008; Edwardson et al., 2010). In 2010, Edwardson et al. showed that using an ActiGraph 5-sec epoch length resulted in greater minutes spent in sedentary time and vigorous PA as compared with a 60-sec epoch length. In contrast, McClain et al. (2008) showed that an ActiGraph 5-sec epoch length underestimated time spent in moderate-to-vigorous PA by 7%. Kang et al. (Kang, Barreira, Holbrook, & Rowe, 2010) used 4 ActiGraph accelerometers worn simultaneously to compare the effects of different epoch lengths (1-sec and 60-sec on one hip, and 15-sec and 60-sec on the other hip) on time spent in moderate PA. After reintegrating the recorded epochs into 1-min durations, Kang et al. showed higher counts per min (cpm) when recording movement with a 1-sec epoch versus the 60-sec epoch (4,060 ± 1,239 cpm and 3,972 ± 1,121 cpm, respectively). Kang et al. concluded that researchers should take note that reintegrating epoch lengths of less than 60 sec into 1-min epoch may result in higher cpm than recorded with 1- min epoch lengths.

While some studies have explored the impact of varied epoch lengths on time spent in different intensities of PA, questions remain about the effects of epoch lengths shorter than 1-min on estimating time spent in sedentary behaviors and varied intensities of PA. This study used a cross-sectional design to identify the effects of applying varied durations (1-, 5-, 15-, and 60 sec) of ActiGraph accelerometer epoch lengths on time spent in sedentary behaviors and light-, moderate-, and vigorous intensities of PA.

Materials

The ActiGraph GT3X (ActiGraph, Pensacola, FL) is a tri-axial accelerometer capable of recording movement in three planes (vertical, horizontal, and lateral). The ActiGraph GT3X is capable of storing raw accelerations gathered at 30-100 Hz in 10 Hz increments for periods of up to 31 days. A small compact device at 4.6cm x 3.3cm x 1.9cm, the ActiGraph GT3X is lightweight (19g) and easily worn around the waist. Height in centimeters was measured using a wall-mounted tape measure. Weight in kilograms was measured using a Tanita TF-300 scale (Tanita, Arlington Heights, IL). Body mass index (BMI) was computed as weight in kilograms/height in meters squared.

Methods

A convenience sample of 30 adults (15 men and 15 women), aged 19-55 years, with varied PA levels were recruited by word of mouth from the Arizona State University community. The inclusion criteria required that participants be able to walk without aid and engage in recreational levels of PA. All participants read and signed an informed consent form approved by the University's Office of Research Integrity and Assurance. Each participant wore four accelerometers on an elastic belt with two accelerometers over each anterior superior iliac spine of the hip. Each accelerometer was randomly assigned to the hip placement using a random number generator to record different epoch lengths of 1-, 5-, 15-, and 60 sec. Participants wore the accelerometers in free-living conditions for seven days to assess average weekly time spent in sedentary behaviors and in light-, moderate-, and vigorous-intensity PA levels. Accelerometers were worn from the time the participants woke up in the morning until they went to bed. If a participant removed the monitors for any reason (bathing, swimming, other water-borne activities), then this non-wear time (52 $min \cdot wk^{-1}$) was recorded in a log developed for this study. After scoring the accelerometers, the non-wear times were removed from the final data analysis.

Data were scored using the ActiLife 6.0 software (ActiGraph, Pensacola, FL). Intensity cut-points were determined using Matthews' (Matthews, 2005) cut-points for sedentary behaviors (<100 cpm) and light-intensity PA (100-1951 cpm) and Freedson's (P S Freedson et al., 1998) cut-points for moderate- (1952-5723 cpm), and vigorous-intensity PA (>5724 cpm). Both sets of cut-points were created using a 60-sec epoch. Cut-points for the other epoch lengths were transformed from the 60-sec cut-points using the following method. The 60-sec cut-points were divided the corresponding number of epochs (e.g. divided by 60 for the 1-sec epoch; divided by 12 for the 5-sec epoch, and divided by 4 for the 15-sec epoch) to determine the cut-points for the shorter epochs. Table 7 shows a side-by-side comparison of the different times for the epoch lengths and their respective cut-points). To compare the time spent in sedentary behaviors and light-, moderate-, and vigorous-intensities between each epoch data collection setting, counts from the epoch lengths were summed and reported as minutes for each activity intensity level.

Table 7.

ActiGraph GT3X Count Cut-points for Activity Intensity by Epoch Length

Epoch Length	**Sedentary**	**Light**	**Moderate**	**Vigorous**
1 Sec	<2	2-32	33-95	>95
5 Sec	<7	8-163	164-477	>477
15 Sec	<25	25-488	489-1431	>1431
60 Sec	<100	100-1951	1952-5723	>5724

Data analyses were conducted using SAS 9.2 (version 9.2, Cary, NC). Means and standard deviations were computed for all variables. A repeated measures ANOVA was conducted to determine differences in minutes of sedentary behaviors, light-, moderate-, and vigorous-intensity activity by epoch length. The independent variables were the epoch lengths (1-, 5-, 15-, and 60-seconds). The dependent variable was minutes spent in each intensity level. This analysis was selected to account for multiple measures being conducted simultaneously on a single individual. Tukey's HSD tests were performed post-hoc to determine significant group differences. The level of significance was set at $p < .05$.

Results

Table 8 shows the descriptive data for the study sample. Participants in this study were between 20 and 41 years. Body weight ranged from 73.6 to 134.7 kg in males and 53.6 to 78.6 in females. Accordingly, BMI was lower in females than the males.

Table 8

Means ± SD and (Ranges) for Descriptive Characteristics of Study Sample

	Males (n = 15)	Females (n = 14)
Age (yrs)	24.8 ± 2.9 (20 - 28)	26.7 ± 6.3 (20 - 41)
Height (cm)	182.1 ± 8.4 (169.0 – 195.0)	164.9 ± 7.0 (152 - 178.0)
Weight (kg)	100.9 ± 20.7 (73.6 – 134.7)	63.7 ±9.2 (53.5 – 79.2)
Body Mass Index ($kg \cdot m^{-2}$)	30.2 ± 4.2 (24.9 – 38.1)	23.5 ± 3.6 (19.7 – 30.6)

Table 9 shows differences in the mean minutes spent in different intensity levels obtained using 1-, 5-, 15-, and 60-sec epoch lengths. Significant differences were observed between the minutes accumulated in sedentary behaviors and in light-intensity PA's across the different epoch lengths. For sedentary behaviors, significantly higher minutes were observed for the 1-sec epoch vs. the 5-sec ($F = 2.51$, $p = .012$), 15-sec ($F = 5.16$, $p<.001$) and 60-sec epoch lengths ($F = 9.01$, $p < .001$). Differences also were observed between the 5-sec, 15- (F = 2.65, p = .008) and 60-sec epoch lengths (F = 6.50, p < .001); and between the 15-sec and the 60-sec epoch lengths (F = 3.85, p < .001).

For light-intensity PA, minutes accumulated from the 1-sec epoch length were significantly less than the 5-sec (F = 2.82,p = .005), 15-sec (F = 5.60, p < .001), and 60-sec epoch lengths (F = 9.98, p < .001). Significant differences were observed between the 5-sec epoch and the 15- (p < .01) and 60-sec epoch lengths (p < .001). A significant difference also was observed between the 15-sec and the 60-sec epoch lengths (p < .001). No differences were observed for time spent in moderate- and vigorous-intensity PA's across epoch length.

Table 9

ActiGraph GT3X Means (SD) for Minutes Accumulated in Sedentary Behaviors, Light-, Moderate-, and Vigorous-Intensity Activity Categories

Epoch Length	**Total Time**	**Sedentary**	**Light**	**Moderate**	**Vigorous**
1 Sec	5,633 (649)	4,849[abd] (476)	441[abe] (161)	285 (136)	55 (81)
5 Sec	5,633 (649)	4,588 [ab] (463)	734 [ac] (258)	268 (142)	40 (62)
15 Sec	5,633 (649)	4,312 [a] (445)	1,023 [a] (361)	255 (126)	39 (77)
60 Sec	5,631 (649)	3,912 (468)	1,479 (523)	197 (129)	39 (88)

Note: Epoch lengths are integrated to represent a 60-sec epoch length

Note: Cut-points were determined using modified Freedson (Freedson et al., 1998) and Matthews' (Matthews, 2005) cut-points

a - significantly different from 60 second epoch at p < .001 b – significantly different from 15 second epoch at p <.001

c – significantly different from 15 second epoch at p <.01 d – significantly different from 5 second epoch at p <.001

e – significantly different from 5 second epoch at p <.01

Discussion

The results from this study highlight the importance of using shorter epoch lengths with the ActiGraph accelerometer to assess time spent in sedentary behaviors and in light-intensity PAs. By shortening the epoch from 60-sec to 1-sec, an additional 937 $min \cdot wk^{-1}$ were spent in sedentary behaviors and a decreased 1,038 $min \cdot wk^{-1}$ were spent in light-intensity PA. These differences in weekly PA levels were significantly different at the $p < .05$ level. While not statistically significant, 1.5 to 2.0 times more minutes was spent in moderate- and vigorous-intensity PAs when using a 1-sec epoch as compared with a 60-sec epoch length. Consistent across all intensities was a gradient for the time across the epoch lengths. Shorter epoch lengths resulted in an increased amount of time spent in sedentary behaviors, and moderate- and vigorous-intensity PAs. However, shorter epoch lengths result in a decreased amount of time in the light-intensity PAs. No significant differences were observed in the total time recorded for each epoch length. This indicates that the differences in time spent in different activity intensities and sedentary behaviors were due to differences in the epoch lengths rather than the time spent in each activity intensity.

This study shows the impact of using a 60-sec epoch length to characterize movement intensities as time spent in sedentary behaviors may be underestimated and time spent in light-intensity PAs may be overestimated as compared with shorter epoch lengths. This misclassification has important implications for research in the health effects of sedentary behaviors and light-intensity PAs.

Using the 2003-2004 NHANES database, Matthews et al. (2008) reported that Americans spent 55% of their daily time in sedentary behaviors. In this study, using a 60-sec epoch length, participants spent 69% of their time in sedentary behaviors while when a 1-second epoch was used to assess sedentary behaviors, participants spent 86% of total time in sedentary behaviors. Additional studies are needed to understand the relationship that exists between differences in epoch lengths and health-related outcome measures. Because of the increasing concern about the amount of time spent sedentary by individuals in the US, further research needs to be conducted to understand the detrimental effects of being sedentary on individual and public health outcomes. This study has the potential to increase accuracy in the objective assessment of time spent in sedentary behaviors and provide increased precision in sedentary behaviors and health outcomes research.

While not significantly different, participants in averaged 28 $min \cdot d^{-1}$ more in moderate intensity PA with an epoch length of 5 sec length and 41 $min \cdot d^{-1}$ more using a 1-sec epoch length as compared with a 60-sec epoch length. This has important implications when assessing the proportion of adults who are meeting the PA Guidelines (DHHS, 2008). The benefit of using 1- and 5-sec accelerometer epoch lengths to integrate time spent in different intensities is that they integrate rapidly changing movements of the same intensity into a summary intensity score as compared to longer epoch lengths that may integrate movements of varying intensities into an averaged intensity level. Additional studies are needed to confirm the findings observed in this study regarding time spent in moderate- and vigorous-intensity PAs.

The stepped dose-response effect observed between the time spent in sedentary behaviors and PA intensities with different epoch lengths indicates varied precision in recording time spent at different intensities. The 1-sec epoch length assessed more time in the sedentary behaviors and moderate- and vigorous-intensity PA categories at the expense of time spent in light PA relative to the 60-second epoch. The 5- and 15-sec epoch lengths showed similar patterns but with smaller difference in time spent in each intensity level than the 1-sec epoch. Application of the epoch length in research settings should reflect the purpose of the study as using a 1-sec epoch length will increase the time spent in sedentary behaviors at the cost of less time spent in light-intensity behaviors. Comparison of the epoch lengths in a cross-sectional or causal study design with health indicator outcomes can show the impact of using varied epoch lengths on the strength of associations between sedentary behaviors and PA intensities and health outcomes.

Results from previous studies have reported significant differences between varied epoch lengths and time spent in sedentary behaviors and PA intensities (Kang et al., 2010; McClain et al., 2008). McClain et al. compared the output from a single accelerometer collecting data in 5-second epochs to re-integrated epochs of 10-, 15-, 20-, 30-, and 60-second epochs. They reported that 5-second epochs reported the least amount of error of any of the epoch lengths. Kang et al. compared two accelerometers worn simultaneously during a walking protocol with different epoch lengths (1-second, 60-seconds). Data from the 1-second epoch were re-integrated into a 60-second epoch. No significant differences were found between the two epoch lengths in assessing activity level. Differences in the protocols and accelerometers used may have resulted in differences between the current study and the other studies. McClain et al. had participants wear only one accelerometer and used post-hoc data programming to re-integrate the data into different epoch lengths. Additionally, only 30 minutes of structured activity were recorded by McClain et al. The current study differed in the use of four accelerometers worn simultaneously and each programmed with different epoch lengths, randomized for wearing position on the participant's hips. By using different accelerometers to collect the data, data were not reintegrated, thus allowing for independent analysis of each accelerometer epoch length. Also, this study differed from the Kang et al. study by assessing movement in a free-living setting as compared to a controlled environment.

As with all studies, the current study has strengths and limitations that impact the external validity of the study. The strengths of this study included, 1) the study used multiple accelerometers with different epoch lengths to compare time spent in sedentary behaviors and different intensity of PAs; 2) the data were collected in a free living setting that allows for further understanding of activity patterns performed in real life; 3) non-wear time was determined by written log with missing data removed from analysis; and 4) data were re-integrated to 60-sec epochs using multiples of the recorded epoch length. Based on the Commutative Property of Multiplication, there were no significant differences in the computed 60-sec epoch lengths for each cut-point. Limitations of the study are those that affect internal and external validity, 1) a convenience sample that limits ability to generalize the findings to other populations that differ from the participants in this study; 2) a relatively small sample size (n=30) that may have limited the power to detect significant differences between time spent in moderate- and vigorous-intensity PA with different epoch lengths; and 3) lack of comparison of the time spent in different intensities with health indicators that could show the impact of the using epoch lengths shorter than 60-sec on sedentary behavior and PA intensity and health relationships. Additional research is needed to replicate these findings and to better understand the relationship between accelerometer epoch lengths and the indicators of health status. Although shorter epoch lengths may be more sensitive to measuring sedentary behaviors and selected PA intensities, the tradeoff between the sensitivity of assessment with a 1-sec epoch and the ability to correctly assess typical movement patterns and health outcomes should be examined.

Conclusion

This study contributes to understanding how the use of varied accelerometer epoch lengths change the time spent in sedentary behaviors and different PA intensities. As compared with a 60-sec epoch length, epochs of 1-, 5-, and 15-sec resulted in more time spent in sedentary behaviors, moderate- and vigorous-intensity PAs and less time spent in light-intensity PA. The added discrimination in assessing time in varied intensities should be confirmed in other studies. The impact of shortened epoch lengths also should be evaluated in studies comparing time spent in varied intensities of PA and indicators of health outcomes.

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Chapter 7

ASSESSMENT OF SEDENTARY BEHAVIORS AND LIGHT-INTENSITY ACTIVITY USING MULTIPLE DEVICES

Abstract

Purpose. To examine the accuracy of three measurement devices (ActiGraph GT3x+, ActivPAL, and SenseWear Armband) in assessing sedentary behavior and light-intensity physical activity (PA) against a referent measure of oxygen uptake (Oxycon Mobile).

Methods. 16 adults (8 males, 8 females) wore the four measurement devices while performing 7 activities (walking at 1.0 mph, 1.5 mph, 2.0 mph, cleaning a kitchen, standing and reading, typing at a computer, and playing board games) classified in the 2011 Compendium of Physical Activities between 1.2 and 1.8 METs or were unmeasured activities that were light-intensity in nature. Activities were classified as either sedentary or light-intensity according to the oxygen uptake, and the other measurement devices were compared against oxygen uptake for accuracy in measurement. Mean absolute percent error (MAPE) was used to calculate measurement accuracy.

Results. The SenseWear Armband measured treadmill walking accurately (0% MAPE), but activities requiring arm movement were less accurate (typing - 50.00% MAPE). The ActivPAL also measured treadmill walking accurately (1.88% MAPE) but misclassified standing activities (reading - 86.88% MAPE). The ActiGraph GT3X+ misclassified activities with slow (<1.5 mph) walking (1.0 mph - 62.05% MAPE).

Conclusion. The measurement device used to assess sedentary behavior may impact the amount of time spent in light-intensity PA or sedentary behaviors. Researchers

should use caution when selecting a measurement device if the goal is to measure sedentary behaviors. Monitors designed to assess PA may not accurately assess sedentary behaviors.

Introduction

Physical activity (PA) has positive health benefits associated with lower levels of hypertension (Roque et al., 2012), diabetes (Rizzo et al., 2008), and cardiovascular disease (McAuley et al., 2012). In addition, individuals who engage in regular moderate-intensity physical activity (PA) have lower mortality rates than sedentary individuals (Arthur S. Leon et al., 1987; Morris & Crawford, 1958b; Patel et al., 2010). Accordingly, U.S. National Physical Activity Guidelines were released in 2008 recommending from 150-300 minutes per week in moderate-intensity PA, 75-150 minutes per week in vigorous-intensity PA, or a combination of the two doses to achieve optimal health benefits from regular PA (DHHS, 2008).

The first recommendation in the U.S. Physical Activity Guidelines called for people to avoid sedentary behaviors. An analysis of the 2003-2004 NHANES data, showed adult men and women spend nearly 54.9% (7.7 hours per day of waking time) in sedentary behaviors (Matthews et al., 2008). Within the past decade, studies of the association between time spent in sedentary behaviors and risks for chronic diseases showed abnormalities in lipid metabolism mechanisms of decreased lipoprotein lipase activity (Hamilton et al., 2008), increased adiposity (Hamilton et al., 2007), and impaired glucose tolerance (Healy et al., 2007a). Equally concerning is research showing alterations in chronic disease risk factors among adults who meet PA guidelines, but spend large amounts of their day in sedentary behaviors(Owen et al., 2010). Despite the emerging research about the hazards of sedentary behaviors, adults continue to spend large proportions of the day engaged in sedentary behaviors a (Tudor-Locke, Johnson, & Katzmarzyk, 2010).

While there has been some uniformity in the objective assessment of PA, there is little consensus on how to assess sedentary behaviors. Accelerometers are frequently used to assess PA and sedentary behaviors. The ActiGraph accelerometer has been used most often as an objective measure of PA assessment. To translate the acceleration data into time spent in PA behaviors, Freedson et al. developed cut-points to detect light-, moderate-, and vigorous intensity PA (Freedson, Melanson, & Sirard, 1997). These cut-points have been used to determine time spent in varying intensities of PA and determine the proportion of adults meeting PA recommendations. To identify the time spent in sedentary behaviors using an accelerometer, Matthews et al. (Matthews, 2005) developed a cut-point of 99 counts or less per minute. There has been some concern about the accuracy of Matthew's cut-point to assess sedentary behaviors (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011). In addition, Kozey-Keadle et al. suggested a higher cut-point is needed to reflect time spent in sedentary behaviors (Kozey-Keadle et al., 2011). Other studies question the ability of the ActiGraph when worn at the hip level to reflect sedentary behavior as well as other accelerometers in the marketplace. For example, the ActivPAL is an accelerometer worn on the thigh that identifies time spent in supine, sitting, and standing postures (Hart et al., 2011). Studies show the ActivPAL is accurate in reflecting time spent in sedentary behaviors. But the instrument alone is insufficient to reflect both sedentary behaviors and PA as the ActivPAL lacks the ability to determine activity intensity (Davies et al., 2011). Other accelerometers can be used to assess time spent in lower levels of PA, including sedentary behaviors. The SenseWear Armband is an arm-worn accelerometer capable of measuring both activity intensity and duration. It has been used to assess activity level and patterns of sedentary behavior in adults (Scheers, Philippaerts, & Lefevre, 2012).

There are many types of accelerometers available to measure PA and sedentary behaviors. As most of these instruments have been evaluated for accuracy to assess PA, there is little need to evaluate them further. However, the accuracy of these instruments to assess sedentary behaviors is unclear. Thus, the goal of this study was to examine the accuracy of four accelerometers to assess seven different sedentary-to-light activities in adults with a variety of PA and sedentary behaviors.

Methods

Sixteen participants (n = 8 men, n = 8 women) with ages 19-47 were assessed at two different sessions on the 7 activities. Each session took approximately 1.5 hours to complete. As part of the first session, height was assessed using a wall-mounted measuring tape, weight and percent fat were assessed using a Tanita bio-electrical impedance scale (TBF-300, Arlington Heights, IL). Participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to identify any possible health concerns and informed consent. If participants had no risks on the PAR-Q, and were able to walk without any sort of aid, they were eligible for the study. Each participant gave written informed consent to the purpose of the study and an understanding of potential risks.

To assess the ability of objective motion sensors to detect sedentary behaviors, each participant wore four different sensors simultaneously during seven selected activities. The activities were performed twice, with at least 24 hours between trials, and the sensors worn are described below.

Activities performed. Each participant performed activities in a randomly assigned order. Every activity was performed for 7 minutes with 4 minutes of rest between activities. The activities performed were as follows:

1) Walking on a treadmill at 1.0 mph (.45 m/s) – Participants were instructed to walk using their normal gait at 1.0 miles per hour at a 0% grade until the time duration was complete. Participants were also instructed not to use the hand rails for support while walking on the treadmill and to keep silent during the protocol. For the first treadmill task, the participants were instructed on how to step onto a

moving treadmill. In subsequent treadmill tasks, the participants were given no further instruction.

2) Walking on a treadmill at 1.5 mph (.67 m/s) – Participants were instructed to walk using their normal gait at 1.5 miles per hour at a 0% grade until the time duration was complete. Participants were also instructed not to use the hand rails for support while walking on the treadmill and to keep silent during the protocol.
3) Walking on a treadmill at 2.0 mph (.90 m/s) – Participants were instructed to walk using their normal gait at 2.0 miles per hour at a 0% grade until the time duration was complete. Participants were also instructed not to use the hand rails for support while walking on the treadmill and to keep silent during the protocol.
4) Working in the kitchen – Participants were instructed to simulate cleaning a kitchen and dishes using a dry rag. Each participant was allowed to complete the task however he or she typically cleaned a kitchen. Tasks included in cleaning the kitchen were: clearing dishes off the counter space, simulating washing and drying the dishes, putting the dishes in the cupboard, and wiping the counter clean. If a participant finished the task before the allotted time, he or she was instructed to continue to start the complete task again until the time was complete.
5) Reading a book while standing – Participants were instructed to stand in place and read a book silently. If a participant finished the book before the end of the allotted time, he or she was instructed to start reading the book from the beginning until the time was complete.
6) Typing while seated at a computer – Participants were instructed to sit at a computer and were given a paragraph to type. If the participant finished typing the paragraph before the end of the allotted time, he or she was instructed to start

typing the paragraph again from the beginning. Participants were instructed to sit up straight and maintain that posture while typing.

7) Sitting quietly playing a board game – Participants were instructed to be seated and play a board game which required the participant to put five objects in a defined order. Participants also rolled a dice and moved their game piece a number of spaces based on their score obtained from ordering the objects. Participants competed against the researcher to more accurately simulate playing a board game. The participants read the cards silently which instructed which objects were to be placed in the defined order. The game was played until the allotted time was completed.

Motion Sensors. The Oxycon Mobile (Oxycon Mobile™, CareFusion, San Diego, CA) (Perret & Mueller, 2006a) served as the referent measure and worn for all activities performed. Pulmonary gas exchange and ventilation were measured breath by breath using a portable metabolic unit to compute participant oxygen uptake (VO_2). The measured VO_2 was the criterion for deciding if an activity was categorized as sedentary or light-intensity. Any activity with a VO_2 of less than 5.25 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ was considered to be sedentary based on each activities MET values listed in the 2011 Compendium of Physical Activities (Ainsworth et al., 2011). The Compendium of Physical Activities classifies activities according to metabolic equivalencies (METs). A MET is calculated by dividing the oxygen cost of the activity by 3.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$, the standardized unit for resting metabolic rate.

Scoring for the ActiGraph was based on recording the seconds spent in movement and non-movement counts using the ActiGraph GT3X+ (ActiGraph, Pensacola, FL). The ActiGraph GT3X+, worn on the hip over the right anterior superior iliac spine, recorded individual accelerations in raw data format, which were transformed into counts per 15-second epoch. The data were downloaded onto a computer and analyzed using the ActiLife 5.2 software. The 15-second counts were classified into either a sedentary (<25 counts) or light-intensity activity (≥ 25 counts) based on the Matthews and Freedson cut-points (Freedson et al., 1997; Matthews, 2005).

The SenseWear Armband (BodyMedia, Inc., Pittsburgh, PA) was worn on the dominant arm of the individual. The SenseWear records the intensity of an activity or sedentary behavior using the dual-axis accelerometer in raw accelerations. The instrument classifies the movement into either sedentary or light intensity activity using proprietary pattern recognition software. Any patterns recognized as less than 1.5 METs were classified as sedentary and patterns greater than 1.5 METs were classified as light intensity.

The ActivPAL (PAL Technologies Ltd, Glasgow, Scotland) is an accelerometer based postural assessment device capable of assessing time spent sitting, standing, and walking. The ActivPAL was worn on the anterior portion of the right thigh. The data were downloaded using the manufacturer's docking device and each 15-second epoch was scored based on the body position. The position most frequently assessed by the ActivPAL determined the classification of sedentary (sitting) or light (standing or walking) intensity activity.

Data Cleaning and Analysis. Data were downloaded from the devices after the cessation of the final activity. Researchers kept a written record of the time each activity was performed. To ensure that a steady state of VO_2 had been attained during each activity, the first two minutes (minutes 1-2) of data for each task from the Oxycon Mobile data were dropped from analysis. The final minute of data (minute 7) for each task from the Oxycon Mobile also was dropped to ensure steady state data were obtained. Thus, minutes 3-6 were used for the VO_2 data were used as the referent data.

The same data cleaning protocol as described for the Oxycon Mobile VO_2 data was used for each monitor. Accordingly, minutes 3-6 of each task were utilized to identify the intensity of movement for each monitor.. Only two of the monitors (ActivPAL, ActiGraph GT3X+) were capable of summarizing data an epoch length of 15 seconds. Data from these monitors were transformed into 15-second epochs for data analysis to match the 15-second epochs of the Oxycon Mobile. The SenseWear was capable of summarizing the data using a 60-second epoch. Thus, four 15-second VO_2 epochs from the Oxycon Mobile were summed to create a 60-second epoch to compare VO_2 and SenseWear data.

After the data had been cleaned, analysis was performed using SPSS version 20 (SPSS Inc., Chicago, IL). Data for each of the 16 epochs for the 15-second epoch devices (reflecting 4 minutes of data per activity performed) were summed to establish means and standard deviations (or frequencies for the ActivPAL) for each activity. Data for the 4 epochs from the 60-second epoch device (SenseWear) were summed and means and standard deviations were computed.

Data were then categorized as being either sedentary behavior or light intensity with dichotomous indicator variables determined for each monitor. The Oxycon Mobile data were transformed from $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ into METs by dividing the 16 15-second VO_2 values by a standardized MET score of 3.5 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$. Activities less than 1.5 METs were categorized as sedentary behaviors. Activities greater than or equal to 1.5 METs were categorized as light-intensity activities. The SenseWear outputted activity data as a METs score. Similarly, activities less than 1.5 METs were categorized as sedentary behaviors and activities greater than or equal to 1.5 METs were categorized as light intensity. Epochs from the ActiGraph GT3X+ were scored as sedentary behavior if there were less than 25 counts per 15-second epoch (100 counts/4). If there were 25 or greater counts in an epoch, it was scored as light intensity activity. Data for the ActivPAL were recorded over a 15-second epoch to reflect the frequently occurring behavior over the epoch length. The ActivPAL data were outputted as a 1 for sedentary behaviors, 2 for standing behaviors, and 3 for walking behaviors. For data analysis, standing and walking were combined into one category to reflect light-intensity activity.

Mean absolute percent error was calculated using the equation below:

$$(\text{Measured Score} - \text{True Score})/\text{True Score} * 100$$

The true score was the referent criterion (VO_2) obtained from the Oxycon Mobile. The measured score was obtained from the comparison monitors (ActiGraph, SenseWear, ActivPAL). If a monitor reported an epoch as sedentary when the Oxycon Mobile reported the epoch sedentary, the epoch was considered to be correctly assessed and was scored as a 1. Similarly, if the measurement device reported an epoch as light-intensity activity and the Oxycon Mobile reported it as light-intensity activity, the epoch was considered correctly assessed and scored as a 1. If the measurement and referent devices reported different activity intensities for the epoch, the measurement device was considered incorrect and scored as a 0. Using these dichotomous data, the mean absolute percent error and standard deviation was calculated and reported for each measurement device.

As each task was performed twice, the energy cost for each activity and sedentary behavior for each device was assessed for test-retest reliability. Using the dichotomous data scoring of sedentary = 0 and light-intensity = 1, Pearson's correlation was used as the measurement to assess if the devices measured similar intensities from session one to session two.

Results

Table 10 presents the descriptive data for the study sample. Participants ranged in age from 19-47 years. Body weight ranged from 54 kg – 111 kg for males and 57 kg – 69 kg for females.

Table 10

Means (SD) for Participant Characteristics

	Males n = 8	Females n = 8
Age (years)	25.5 (8.8)	25.0 (9.0)
Height (cm)	178.6 (11.0)	169.0 (7.6)
Weight (kg)	88.5 (17.0)	61.4 (4.2)

Table 11 presents the mean values for each monitor during walking at 1.0 mph. Frequencies are reported for the ActivPAL. The mean absolute percentage error (MAPE) was highest in the ActiGraph GT3X+ (62.05%). The ActivPAL and SenseWear Armband had very low MAPE (1.88 and 0.00, respectively). While the test-retest scores for the ActivPAL and SenseWear showed perfect agreement, the ActiGraph showed more variation from one trial to the next. .

Table 11

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Walking at 1.0 mph

	Oxycon n = 14	ActiGraph GT3X+ n = 11	ActivPAL n = 8	SenseWear Armband n = 13
Mean (SD)	7.85 (1.14) [a]	30.57 (36.23) [b]	-	10.50 (1.68) [a]
Frequency	-	-	-	-
Sitting	-	-	0	-
Standing	-	-	35	-
Walking	-	-	93	-
Mean % Error (SD)	-	62.05 (46.81)	1.88 (3.40)	0.00 (0.00)
Test-Retest (Pearson Correlation)	-	0.634	1.000	1.000

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 12 presents the mean values for each monitor during walking at 1.5 mph. The MAPE scores for all three measurement devices are quite low indicating excellent agreement. The test-retest reliability for ActivPAL and the SenseWear were perfect and the ActiGraph GT3X+ is 0.834 indicating a good level of reliability.

Table 12

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Walking at 1.5 mph

	Oxycon Mobile n = 15[c]	ActiGraph GT3X+ n = 12	ActivPAL n = 9	SenseWear Armband n = 14
Mean (SD)	8.74 (1.20) [a]	98.67 (53.15) [b]	-	12.50 (1.02) [a]
Frequency	-	-	-	-
Sitting	-	-	0	-
Standing	-	-	0	-
Walking	-	-	144	-
Mean % Error (SD)	-	4.81 (10.92)	0.69 (1.56)	0.00 (0.00)
Test-Retest (Pearson Correlation)	-	0.834	1.000	1.000

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 13 presents the mean values for each monitor during walking at 2.0 mph. The MAPE scores for all three measurement devices were below 1% indicating a high level of accuracy in measurement. Each monitors also had perfect Pearson correlation scores indicating excellent reproducibility of scores.

Table 13

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Walking at 2.0 mph

	Oxycon Mobile n = 14[c]	ActiGraph GT3X+ n = 11	ActivPAL n = 8	SenseWear Armband n = 13
Mean (SD)	10.06 (1.18) [a]	262.68 (92.11) [b]	-	12.99 (1.30) [a]
Frequency	-	-	-	-
Sitting	-	-	0	-
Standing	-	-	0	-
Walking	-	-	128	-
Mean % Error (SD)	-	0.48 (1.56)	0.69 (1.56)	0.00 (0.00)
Test-Retest (Pearson Correlation)	-	1.000	1.000	1.000

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 14 presents the mean values for each monitor during the kitchen cleaning activity. The mean number of 15-second epoch counts for the ActiGraph GT3X+ was 8.71 indicating a sedentary activity, but the VO_2 was recorded as a light-intensity activity. This resulted in a high MAPE score for the ActiGraph GT3X+, resulting in a large amount of error in the measurement. Pearson's correlation indicated good test-retest reliability for the ActivPAL but not the ActiGraph or the SenseWear monitors.

Table 14

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Kitchen Cleaning

	Oxycon Mobile n = 14[c]	ActiGraph GT3X+ n = 11	ActivPAL n = 8	SenseWear Armband n = 13
Mean (SD)	6.17 (1.24) [a]	8.71 (11.15) [b]	-	10.57 (2.84) [a]
Frequency	-	-	-	-
Sitting	-	-	0	-
Standing	-	-	125	-
Walking	-	-	3	-
Mean % Error (SD)	-	63.46 (34.95)	29.86 (26.98)	26.79 (33.50)
Test-Retest (Pearson Correlation)	-	0.682	0.805	0.586

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 15 presents the mean values for each monitor during the reading activity. The ActivPAL recorded a high MAPE (86.11%) because the activity required the participant to stand, scoring the activity as light-intensity, whereas the VO_2 score indicated the activity as a sedentary behavior. The test-retest reliability was poor for all monitors indicating a large amount of variance in scores between the two sessions.

Table 15

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Reading While Standing

	Oxycon Mobile n = 14[c]	ActiGraph GT3X+ n = 11	ActivPAL n = 8	SenseWear Armband n = 13
Mean (SD)	4.03 (0.72) [a]	0.13 (0.43) [b]	-	3.71 (0.21) [a]
Frequency	-	-	-	-
Sitting	-	-	0	-
Standing	-	-	128	-
Walking	-	-	0	-
Mean % Error (SD)	-	12.02 (17.38)	86.11 (46.58)	17.86 (27.20)
Test-Retest (Pearson Correlation)	-	0.304	0.495	-0.167

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 16 presents the mean values for each monitor during the typing activity. This activity did have a higher VO_2 level than reading and the VO_2 score reflected occasional bouts of light-intensity activity. The SenseWear had a 50% MAPE score indicating a high level of error in assessing this activity. Test-retest reliability was low for all monitors.

Table 16

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Typing at a Computer

	Oxycon Mobile n = 15[c]	ActiGraph GT3X+ n = 12	ActivPAL n = 9	SenseWear Armband n = 14
Mean (SD)	4.46 (0.78) [a]	0.51 (1.41) [b]	-	6.58 (2.45) [a]
Frequency	-	-	-	-
Sitting	-	-	144	-
Standing	-	-	0	-
Walking	-	-	0	-
Mean % Error (SD)	-	24.11 (24.67)	25.00 (25.10)	50.00 (40.70)
Test-Retest (Pearson Correlation)	-	-0.123	-0.442	0.651

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Table 17 presents the mean values for each monitor during the typing activity. The monitors had similar amounts of error, as indicated by MAPE scores ranging from 17.31-28.57%. The reliability of the ActiGraph GT3X+ was adequate (0.783), while the ActivPAL had very poor test-retest reliability (0.118).

Table 17

Means, Standard Deviation, Mean Absolute Percent Error and Test-Retest Reliability for Playing Board Games

	Oxycon Mobile n = 14[c]	ActiGraph GT3X+ n = 11	ActivPAL n = 8	SenseWear Armband n = 13
Mean (SD)	4.20 (0.68) [a]	1.45 (4.58) [b]	-	5.88 (2.70) [a]
Frequency	-	-	-	-
Sitting	-	-	112	-
Standing	-	-	16	-
Walking	-	-	0	-
Mean % Error (SD)	-	17.31 (13.40)	25.69 (23.02)	28.57 (36.51)
Test-Retest (Pearson Correlation)	-	0.783	0.118	0.483

[a] Data are presented as $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$ [b]Data are presented as counts [c] Sample sizes differ due to missing data points or equipment malfunction for some trials

Discussion

The results from this study highlight that monitor selection for assessing sedentary behaviors is important. Both the SenseWear and ActivPAL were more accurate in assessing sedentary behaviors than the ActiGraph GT3X+ when the devices were compared with the Oxycon Mobile VO_2 values. The reliability of the ActivPAL was highest of the three devices, while the reliability of the SenseWear was poor in non-walking activities.

An oft-used device in physical activity research, e.g., ActiGraph GT3X+, is effective in measuring movement but, as worn on the hip, it has considerable error in measuring sedentary behavior. While the ActiGraph GT3X+ categorized the most intense activity correctly, as well as the activities with no movement, any activity that required movement with the arms or slow movement with the legs was often miscategorized.

Light intensity activities, such as cleaning a kitchen and walking at 1.0 mph, had large amounts of measurement error (34.95% and 62.05%, respectively). The ActiGraph does not appear to be suited to accurately measuring the difference in light-intensity activity and sedentary behaviors.

The SenseWear measured the treadmill activities the most accurately and had relatively low error scores on all the tasks except typing (50.00%). The reason for this may be because it is worn on the arm and tasks utilizing the arms may be misclassified as being more intense than measured. The VO_2 value for this task (4.46 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$) was lower than the SenseWear assessed value (6.58 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$). The SenseWear categorized walking activities accurately with mean absolute percent error (MAPE) scores of 0% for all three walking speeds. These data indicate that the SenseWear is capable of accurately measuring walking intensities and may be effective in monitoring individuals that engage in light-intensity walking on a daily basis. The SenseWear had poor reliability scores on the non-treadmill activities indicating that this may not be a device that measure activities of daily living reliably.

The ActivPAL measured most accurately across activities of daily living and had nearly perfect measures on the treadmill activities. The ActivPAL had the highest MAPE score (86.11) for the reading activity. Because standing was classified as a light intensity, the device recorded the reading activity as light intensity, even though the mean oxygen uptake value (4.03 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$) indicated a sedentary activity. The simplicity of analyzing the ActivPAL output is a strength for the monitor. Since activities can only be classified as one of three positions (sitting, standing, and walking), it allows for more accurate classification of body position. However, the monitor is not as accurate if there are activities that require effort while sitting or standing.

While Hamilton et al. (Hamilton et al. 2007) have defined standing as a light-intensity activity, the oxygen cost of standing in this study classified standing as a sedentary activity defined as < 1.5 METs. Additionally, monitors such as the ActivPAL showed large amounts of measurement error on specific tasks. Because it lacks the ability to measure intensity and only assess posture, this device errors on activities where an individual might be standing, but only expending energy slightly above resting levels.

There were several strengths to this study. First, participants wore the four measurement devices simultaneously so each activity could be monitored within a laboratory. The high level of participant monitoring allowed the researchers to assess if the measurement devices were accurately monitoring the activities. Second, activities were randomized to prevent systematic bias, which allowed the results to improve in accuracy. Finally, activities were selected that were estimated by the Compendium of Physical Activities (Ainsworth et al., 2011) to be near the light-intensity activity threshold of 1.5 METs. This insured that activities performed would aid in understanding the accuracy of assessing sedentary and light behaviors.

This study had several limitations. Most notably, there was a high amount of equipment failure and data recording errors from the devices. The ActivPAL software did not always correctly activate the ActivPAL to record as scheduled. Additionally, the Oxycon Mobile recorded data for two individuals, but the data was corrupted when attempting to save the data for analysis. Second, we included only 8 men and 8 women in the study. This amplified error from missing data due to equipment or signal failure. Larger sample sizes would increase the power to detect similar findings with the referent VO_2 value if the scores were generally similar. Third, participant fidgeting may have contributed to measurement error in the seated activities. During the game activity, one participant had each epoch recorded as standing when the participant was clearly seated.

The leg positioning while seated may have played a role in this measurement error. While participants were given instructions for their postures during each task, individual variation in performing tasks was expected. Last, the slow speed of the treadmill walking activities may have altered the normal stride of the participants and caused them to walk with gaits that were less efficient mechanically and increased the oxygen cost of the movement. This may have accounted for the higher MAPE scores for the ActiGraph GT3X+ on the 1.0 mph walking task.

Conclusion

The results from this study show the ActivPAL monitor as the most capable of accurately distinguishing sedentary behaviors from light-intensity activities. With the exception of the reading activity, the ActivPAL had MAPE scores less than 30%. The SenseWear measured many of the activities accurately, but had a low reliability score. The ActiGraph GT3X+, commonly used in physical activity research, misclassified activities that required slow movements of the legs for ambulation. Care should be used in utilizing ActiGraph GT3X+ data in reporting time spent in sedentary versus light activities with the modified Mathews' and Freedson' cut-points.

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Chapter 8

DISCUSSION

Physical activity and sedentary behavior are pressing public health issues that are directly associated with the increase of chronic disease in the United States and other developed nations. Additional evidence is needed to further understand the effects of common activities on reaching physical activity guidelines. The measurement and assessment of sedentary behaviors is a field that is still developing and needs further refinement to understand optimal methods for measuring sedentary behaviors independently of physical activity. Accurate assessment of both physical activity and sedentary behaviors is important for understanding the health implications of different patterns of physical activity and sedentary behavior.

Project one assessed the oxygen cost of several care-oriented activities. The purpose of this study was to understand the amount of energy expended and activity level reached while performing these activities of caring for others. The results showed that pushing an adult in a wheelchair and pushing an infant in a stroller met the threshold of a moderate-intensity physical activity. These two activities of daily living contribute towards meeting the accumulated minutes of daily physical activity outlined in the 2008 Guidelines for Physical Activity (DHHS, 2008).

Project two assessed the oxygen cost of several home-cleaning activities. The purpose of this study was to understand the amount of energy expended and activity level reached while performing typical activities associated with cleaning a home. The results showed that mopping a floor uses enough energy to be considered a moderate-intensity physical activity. This cleaning activity may contribute daily minutes of mopping floors towards meeting the 2008 Guidelines for Physical Activity (DHHS, 2008).

Project three was designed to assess the impact of accelerometer epoch length on time spent in physical activity categories. Unique to this study, four separate accelerometers were worn to assess each epoch length. The results showed a significant dose-response relationship between epoch length and time spent in sedentary behaviors and light-intensity activity. These data indicated that the traditional 60-second epoch may underestimate the amount of time spent in sedentary behaviors and overestimate the amount of time spent in light-intensity behaviors.

Project four was designed to assess which devices were more accurate in assessing behaviors that could be classified as either sedentary or light-intensity. Three different physical activity monitors were compared with a referent measure to determine which monitors most accurately measured seven different activities. The results showed that the SenseWear and ActivPAL both measured the selected activities more accurately than the ActiGraph GT3X+. However, the SenseWear had poor test-retest reliability on non-walking activities. Care should be taken when selecting a device to assess both physical activity and sedentary behaviors.

The relationship that exists between physical activity and sedentary behaviors is a complex one that needs to be more fully understood. By constantly refining and testing assessment methods for both these constructs, a better understanding of sedentary behaviors, physical activity, and the relationship between them can be grasped.

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