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Associations of Total Activity Counts and Physical Activity Intensity Levels with the Metabolic Syndrome: A Structural Equation Modeling Approach

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I am submitting herewith a dissertation written by Dana Lizbeth Wolff entitled "Associations of Total Activity Counts and Physical Activity Intensity Levels with the Metabolic Syndrome: A Structural Equation Modeling Approach." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Kinesiology and Sport Studies.

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DEDICATION

To Justin Hughes, my fiancé, for his love, support, and encouragement. You continually push me to achieve my dreams, and I am so very grateful.

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ABSTRACT

To clarify the protective benefits of physical activity (PA), epidemiologists and public health researchers continue to seek improved methods of assessing PA. In particular, accelerometers have gained acceptance with researchers as they provide reliable estimates of PA and can record both the amount and intensity of ambulatory movement. However, there is concern that accelerometer data reduction techniques may not provide quantitatively accurate measurements of time spent in various PA intensity categories. One way to circumvent these inaccuracies is to use the accelerometer-derived total activity counts (TAC), which is a more direct expression of what the monitor records.

In order to explore the efficacy of TAC as a measure of PA, this dissertation used data from the 2003 - 2006 National Health and Nutrition Examination Survey to: 1) investigate whether TAC was more strongly associated with cardiometabolic biomarkers than minutes of moderate-to-vigorous PA (MVPA), 2) determine population-referenced TAC percentiles for the U.S. population, and 3) determine which accelerometer-derived measure(s) of PA intensity and volume provided the best fit for assessing the association with the metabolic syndrome.

The first study demonstrated that TAC had stronger associations with cardiometabolic biomarkers than time spent in MVPA bouts of ≥ 10 minutes, suggesting TAC is a more robust measure of PA (Part IV). In the second study, age- and gender- specific population-referenced percentiles for TAC, MVPA, and light PA (LPA) were developed (Part V). This is a different approach to accelerometer data reduction that complements the current method of looking at time spent in intensity sub-categories.

The third study used structural equation modeling to examine whether TAC, MVPA, or MVPA plus LPA provided the best fit for assessing the relationship with the metabolic syndrome

(Part VI). This study also assessed the relative contribution of LPA, MPA, VPA, and TAC to the reduction in the prevalence of the metabolic syndrome. Results indicated a model with TAC provided the best fit for assessing the relationship between PA and the metabolic syndrome. These findings suggest TAC, may be a better measure of PA when examining the reduction in the metabolic syndrome prevalence.

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PART I

INTRODUCTION

The metabolic syndrome is a clustering of cardiometabolic risk factors that include central adiposity, hyperglycemia, elevated blood pressure, and dyslipidemia (elevated triglycerides and attenuated high-density lipoprotein cholesterol [HDL-C])[1]. Within the United States (U.S.), the metabolic syndrome is a growing public health concern with an estimated prevalence in adults ranging from 22.9 to 34.9% depending on the metabolic syndrome definition used[1-3]. Additionally, individuals with the metabolic syndrome are at greater risk of developing and dying from cardiovascular disease and type II diabetes[4-7].

To properly prevent and treat the metabolic syndrome, it is important to understand health behaviors that influence its development. Physical activity (PA) is a modifiable behavior that has consistently demonstrated associations with the risk of the metabolic syndrome[8-13]. At the population level in the U.S., the relationship between PA and the metabolic syndrome has been assessed using data obtained from the National Health and Nutrition Examination Survey (NHANES). The NHANES currently uses both self-report methods and accelerometers to assess participants' PA. While self-report PA has historically been collected as part of the NHANES, the use of accelerometers to assess PA did not begin until the 2003 – 2004 survey cycle. Thus, many studies using NHANES data have relied on self-report measures to determine associations with health outcomes.

Self-reported PA data, collected as part of the NHANES, have been used by researchers to assess the relationship of PA and the metabolic syndrome at the population level. In a study by Park al.[8], utilizing data from NHANES III, the intensities of the most commonly reported leisure-time physical activity (LTPA) (*i.e.,* walking, jogging, swimming, gardening/yard work) were used to develop a PA intensity score, which was defined as the ratio of activity-related metabolic rate to resting metabolic rate. A PA intensity score of ≤ 3.5 classified individuals as

physically inactive, while moderately active corresponded to a score between 3.6 and 14.9 and active a score of ≥ 15. The cut-points for moderately active and active were chosen to represent the 15th and 65th percentile of PA for men and 25th and 75th percentile for women, respectively. Results of this study found inactive men had a 40% increased risk for being diagnosed with the metabolic syndrome compared to their active counterparts. However, there was no significant association found for women[8].

In another NHANES III study conducted by Zhu and colleagues[10], the PA risk score was also used to assess the association of self-reported PA with the metabolic syndrome. Results of this study indicated that being physically active was associated with a 31% and 17% reduction in the risk of being diagnosed with the metabolic syndrome in men and women, respectively[10]. Similarly, a study conducted by DuBose et al.[9] utilized self-report PA data from NHANES III to assess the relationship with the metabolic syndrome. In contrast to the studies by Zhu and Park, this study determined the intensity of self-reported LTPA using the Compendium of Physical Activities, which expresses intensity as metabolic equivalents (METs)[14]. Moderate-intensity PA was defined as 3 – 6 METs and vigorous intensity defined as ≥ 6 METs[14]. Participants were classified as active if they obtained ≥ 5 d/wk of moderate intensity and/or ≥ 3 d/wk of vigorous intensity LTPA. Inactive participants were those who reported no LTPA over the past month. Results of this study indicated that inactive participants had a 45% increase in the odds of being classified as having the metabolic syndrome[9].

Using data from the 1999-2000 NHANES, Ford et al.[11] examined the relationship between self-reported MVPA, sedentary behavior, and the metabolic syndrome. In this study, MVPA was classified into three categories based on the minutes of activity: 0, < 150, and ≥ 150 min/wk. Sedentary behavior was measured by a question which asked respondents how many

hours of television they watched daily over the past 30 days. Results of this study revealed that both MVPA and sedentary behavior were associated with the metabolic syndrome; however there was no interaction between MVPA and sedentary time. Additionally, it was found that individuals who engaged in 0-min/wk of MVPA had almost twice the odds of having the metabolic syndrome compared to those who engaged in 150 min/wk of MVPA[11].

More recently, using data from the 1999 – 2004 continuous NHANES, Churilla and colleagues[12] studied the relationship between the metabolic syndrome and LTPA using two definitions of the metabolic syndrome, developed by the American Heart Association/National Heart Lung and Blood Institute (AHA/NHLBI)[15,16] and World Health Organization (WHO)[17]. Total LTPA was categorized into six levels with the first level comprised of individuals with no self-reported LTPA and the five remaining levels divided into MET$\cdot$ min$^{1}\cdot$ wk^{-1} quintiles of self-reported PA. Results of this study indicated an inverse association between both definitions of the metabolic syndrome and LTPA. Between the two definitions, however, it was seen that the dose of PA necessary to provide protection against the metabolic syndrome varied. Using the WHO criteria, protection began at the 3rd quintile of PA (393 – 736 MET$\cdot$ min$^{1}\cdot$ wk^{-1}), which provided a 30% reduction in risk of the metabolic syndrome. Based on the AHA/NHLBI criteria, significant protection did not begin until the 4th quartile of PA (737 – 1360 MET$\cdot$ min$^{1}\cdot$ wk^{-1}), which reduced the risk of the metabolic syndrome by 35%. Additionally, this study found adults meeting the American College of Sports Medicine/AHA PA recommendations for public health were 39 – 46% less likely to have the metabolic syndrome[12]. These results indicate the reduction in metabolic syndrome risk with increased PA varies between metabolic syndrome definitions.

In another study by Churilla et al.[13], the total volume of PA acquired from leisure-time, domestic, and transportational PA was assessed to determine the association with the metabolic syndrome. Results revealed individuals with higher volumes of total PA and LTPA had significantly lower prevalence of the metabolic syndrome. For both total PA and LTPA, significant protection against the metabolic syndrome was seen starting in the 4th quintile of PA. The volume associated with the 4th quintile, however, was higher for total PA (1261 MET$\cdot$ min$^{1}\cdot$ wk^{-1}) compared to LTPA (736 MET$\cdot$ min$^{1}\cdot$ wk^{-1}). The authors of this study hypothesized the greater volume of total PA necessary for protection was due to the lower intensity of domestic and transportational activities compared to leisure-time activities[13].

Although the relationship between metabolic syndrome and PA has been demonstrated using self-report methods of PA, self-report measures are subject to substantial bias that has been well documented in the physical activity epidemiology literature[18-21]. In contrast, objective measures of PA, such as accelerometers, may provide increased precision and decreased bias when investigating the dose-response relationship and potential threshold effect associated with the metabolic syndrome. However, there are a limited number of studies using the 2003 – 2006 NHANES data to assess the relationship between the metabolic syndrome and accelerometer-based measures of PA[22-24]. Furthermore, these studies use different accelerometer-derived measures of PA, limiting the interpretability of results.

Specifically, Metzger and colleagues[23] explored whether MVPA performed in 1-minute bouts and accumulated in different patterns across the week (*e.g.,* weekend warrior, consistent accumulation across the week, etc.) was associated with the metabolic syndrome. Using data from the 2003 – 2004 NHANES, a structural equation model (SEM) was proposed and subsequently tested in order to determine associations between the pattern of MVPA

accumulation, risk factors of the metabolic syndrome, and classification of the metabolic syndrome. In this study MVPA was classified as the average daily minutes with counts above 2020. Results of the study revealed that individuals accumulating the weekly recommended amount of PA had a lower risk of developing the metabolic syndrome. However, no differences in metabolic syndrome risk were seen when examining the pattern in which MVPA was accumulated throughout the week [23].

In another study, Sisson et al.[24] used 2005 – 2006 NHANES data to determine the association of accelerometer-derived steps per day and the odds of having the metabolic syndrome. Results of this study indicated for every 1,000 steps/day accumulated the odds of having the metabolic syndrome decreased by 10%. In addition, active to highly active individuals (≥10,000 steps/day) had 72% lower odds of the metabolic syndrome compared to their sedentary counterparts[24].

Accelerometer-based measures of PA were also used by Jansen et al.[22] to investigate the relationship with the metabolic syndrome. Using the 2003 – 2006 NHANES, the association between the metabolic syndrome and accelerometer-derived minutes of moderate-intensity PA (MPA), vigorous-intensity PA (VPA), and MVPA performed in 1-minute bouts was examined. The intensity of activity was first determined using the Freedson[25] regression equation which estimated the METs from the counts/minute obtained from the accelerometer. MET thresholds, consistent with the Compendium of Physical Activity[14], were then used to classify the intensity of PA. Results of this study revealed that the odds of the metabolic syndrome decreased with increasing levels of MPA, VPA, and MVPA. Independent associations of VPA and MPA with the metabolic syndrome were also found. It was also found that approximately 75 minutes/week

of VPA provided a greater reduction (37.1%) in the prevalence of the metabolic syndrome than an equivalent volume (150 minutes/week) of MPA (15.5%)[22].

In another study, the association of the metabolic syndrome and related risk factors with PA accumulated in ≥ 10-min and < 10-min bouts was examined[26]. The authors of this study used the 2003 – 2006 NHANES data and defined MVPA as minutes with ≥ 2020 counts. Results of this study revealed both bout and non-bouted MVPA significantly reduce the risk of the metabolic syndrome and related cardiometabolic risk factors. Non-bouted MVPA was also found to protect against classification of the metabolic syndrome after adjusting for bouted MVPA (OR: 1.02; $p = 0.006$), suggesting non-bouted MVPA may provide benefits for cardiometabolic health[26]

While these studies provide evidence for the use of accelerometer-derived PA measures, there is also concern that that accelerometers may not provide quantitatively accurate measurements of time spent in various intensity categories (*e.g.,* sedentary, light, moderate, and vigorous)[27-30]. One way to circumvent these inaccuracies is to use the accelerometer-derived total activity counts per day (TAC), which is a more direct expression of what the monitor records[31,32]. More importantly, TAC is a measure of the total PA volume, and it incorporates all intensity categories, weighting each minute according to the intensity of the movement.

Recently, Wolff and colleagues conducted two pilot studies which explored the importance of a global, objective measure of PA using TAC derived from hip-worn accelerometers (Parts IV-V). The first pilot study, which utilized accelerometer data obtained from the 2003 – 2006 NHANES, demonstrated that TAC had stronger associations with cardiometabolic biomarkers (*e.g.*, blood pressure, body mass index, cholesterol, etc.) than traditional accelerometer-derived minutes spent in MVPA bouts of 10 minutes or greater (Part

IV). Five cardiometabolic risk factors comprising the metabolic syndrome were more strongly related to TAC than MVPA: waist circumference, fasting glucose, triglycerides, HDL-C, and systolic blood pressure. One risk factor, diastolic blood pressure, was not found to have significant associations with either TAC or MVPA. These results suggest that TAC is a more robust measure of PA, as it is more closely related to health indicators associated with the metabolic syndrome (Part V).

In the second pilot study conducted by Wolff and colleagues (Part V), age- and gender-specific population-referenced percentiles for TAC, MVPA, and light PA (LPA) were developed. The population-reference values provide researchers with a measure of the total volume of PA that can be expressed relative to other adults (*i.e.,* as percentiles). Additionally, this is a different approach to accelerometer data reduction that complements the current method of looking at time spent in intensity sub-categories (Part V).

Definitions

The following section provides definitions of commonly used terms and variables discussed in this study. Many of the variables discussed (i.e., the metabolic syndrome, and accelerometer-derived PA measures) have multiple definitions. Therefore, these definitions should not be applied in Part II, the review of literature.

1. Metabolic Syndrome: a clustering of cardiometabolic risk factors that increase an individual's risk of heart disease, stroke, and diabetes[1, 4-7]. The present study used the AHA/NHLBI[15,16] definition of the metabolic syndrome which requires an individual meet three of the following five risk factor criteria:
    a. Central adiposity: defined as a waist circumference > 102 centimeters (cm) in men and > 88 cm in women;

b. Elevated triglycerides: defined as triglyceride levels ≥ 150 milligrams per deciliter (mg/dL) or undergoing pharmacological treatment;

c. Attenuated high-density lipoprotein cholesterol (HDL-C): defined as < 40 mg/dL in men and < 50 mg/dL in women, or undergoing pharmacological treatment;

d. Elevated blood pressure: defined as blood pressure ≥ 130 / ≥ 85 mmHg, or undergoing pharmacological treatment; and,

e. Impaired fasting glucose: defined as fasting glucose ≥ 100 mg/dL or undergoing pharmacological treatment.

2. Activity Counts: the raw output of an accelerometer. The ActiGraph 7164 accelerometer used in this study produces activity counts through a three step process. First, the bidirectional voltage signals recorded by the accelerometer are full-wave rectified to convert negative signals to positive signals. Second, an integration algorithm is applied to the data to determine the maximal value for each 1-minute epoch, reflecting the raw counts for each 1-minute period. Third, the integration algorithm sums the raw counts to produce activity counts[33].
3. Total Activity Counts (TAC): in this study, TAC represented the sum of all activity counts accumulated on valid accelerometer wear days.
4. Light-intensity Physical Activity (LPA): in this study, LPA was defined as the total number of minutes with 100 – 2019 counts/minute[30], averaged across all valid wear days.
5. Moderate-intensity Physical Activity (MPA): in this study, MPA was defined as the total number of minutes with 2020 – 5998 counts/minute[30], averaged across all valid wear days.
6. Vigorous-intensity Physical Activity (VPA): in this study, VPA was defined as the total number of minutes with ≥ 5999 counts/minute[30], averaged across all valid wear days.

7. Structural Equation Modeling (SEM): a multivariate statistical technique that tests the relationships between exogenous and endogenous latent constructs, the loadings of manifest variables onto constructs, and measurement and prediction error[34-36].
8. Latent Construct: an unobservable measure that is comprised of multiple manifest variables that are hypothesized to underlie the construct[34-36]. In SEM, latent constructs are indicated by ovals or circles.
9. Exogenous Variable: variables that are not dependent on any other variables and are therefore thought of as the independent variables[34-36]. In SEM, these variables have no arrows pointing to them.
10. Endogenous Variable: a variable that is dependent on at least one other variable. Endogenous constructs are considered mediating or dependent variables[34-36]. These variables have at least one arrow pointing to them in the structural model.
11. Manifest Variable: a directly observed or measured variable. In SEM, manifest variables are indicated by rectangles or squares[34-36].
12. Factor Loading: represents the correlation between each manifest variable and the latent construct[34-36]. A higher factor loading indicates a stronger contribution of the manifest variable to the latent construct.
13. Standardized Regression Weights (Path Weights): indicate the association of latent constructs with other variables or constructs specified in the model[34-36]. Standardized regression weights reflect the standard deviation change in an outcome variable for every standard deviation unit change in a predictor variable. For example, for every standard deviation increase in MPA the prevalence of the metabolic syndrome goes down by 0.512 standard deviations.

Statement of the Problem

The purpose of this study was to use a structural equation modeling (SEM) approach to examine the relationship between hip-worn accelerometer-derived measures of PA (*e.g.,* MVPA, LPA, and TAC) and the metabolic syndrome in a representative sample of U.S. adults. Emphasis was placed on determining whether TAC is a viable alternative to other accelerometer-based measures of PA when studying the metabolic syndrome. Posed below are the specific research questions addressed by this study.

Research Questions

1. Does a SEM model measuring the relationship between the metabolic syndrome and PA with MPA and VPA (Appendix A, Figure A.1) perform as well as a model measuring PA with LPA, MPA, and VPA (Appendix A, Figure A.2)?
2. Does a SEM model measuring the relationship between the metabolic syndrome and PA with MPA and VPA (Appendix A, Figure A.1) perform as well as a model measuring PA with TAC (Appendix A, Figure A.3)?
3. Does a SEM model measuring the relationship between the metabolic syndrome and PA with LPA, MPA and VPA (Appendix A, Figure A.2) perform as well as a model measuring PA with TAC (Appendix A, Figure A.3)?

Significance

The purpose of this study was to determine the relative contribution of accelerometer-derived measures of PA in the reduction in the prevalence of the metabolic syndrome. This is the first study to determine if TAC has greater associations with underlying risk factors of the metabolic syndrome compared to various intensities of PA (*e.g.,* LPA, MPA, and VPA). Specifically, the results obtained from the structural equation models analyzed in this study will

guide future studies examining accelerometer-based PA metrics with the metabolic syndrome. Additionally, the results of this study may provide evidence for the use of the TAC metric in future studies examining the metabolic syndrome and other health outcomes.

Delimitations

For this study, the sample was limited to adults ≥ 20 years of age who participated in a fasting morning examination in the 2003 – 2006 NHANES. Participants with less than four days of accelerometer data that included ≤ 10 hours of wear time, and pregnant or lactating women were excluded from the analyses.

Limitations

The present study has several limitations inherent within its design. Therefore, the findings must be interpreted with caution. The limitations are described below.

1. Due to the cross-sectional design of this study, causality cannot be determined.
2. Accelerometer counts are dependent on the characteristics of the specific brand of PA monitor. This study used an ActiGraph 7164 accelerometer and thus, counts obtained from other PA monitors are not directly comparable.
3. The choice of accelerometer cut-points may over- or under-estimate the amount of time spent in PA intensity sub-categories. Thus, the cut-points used in this study may not reflect the true volume of LPA, MPA, and VPA accumulated by participants.
4. Other health variables (*e.g.,* smoking, alcohol intake, and poor diet) involved in the interplay between PA and the metabolic syndrome were not controlled for in this study. In particular, dietary factors (*e.g.*, saturated fat levels and caloric intake) were not controlled for in this study due to the complexity of the dietary data file within the NHANES.

5. SEM was performed using AMOS 20.0 (IBM SPSS AMOS 20, AMOS Development Corporation, Armonk, NY). This software is unable to account for complex sampling design inherent within NHANES. Therefore, the ability to discuss trends among U.S. adults is limited in this study.

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PART II

REVIEW OF LITERATURE

The metabolic syndrome is defined as clustering of cardiovascular and metabolic risk factors that include central adiposity, hyperglycemia, elevated blood pressure, and dyslipidemia[1]. Physical activity (PA) is a modifiable behavior that has been shown to reduce an individual's risk for developing the metabolic syndrome. The accuracy of PA measures, however, may impact the strength of the relationship with the metabolic syndrome. Recently, accelerometers have gained acceptance in the research community as they provide reliable estimates of PA and can record both the amount and intensity of an individual's ambulatory movement[2-4]. Despite the ability of accelerometers to capture the intensity of ambulatory activity, issues exist regarding their ability to accurately identify the number of minutes spent in light, moderate, and vigorous intensity categories[5-7].

The following review of literature will discuss: 1. the metabolic syndrome; 2. a review of studies examining the association between self-reported PA and the metabolic syndrome; 3. a review of studies examining the association between objectively-measured PA and the metabolic syndrome; and 4. accelerometer data reduction techniques. Sections 2 and 3 will first discuss National Health and Nutrition Examination Survey (NHANES) studies, followed by other U.S.-based studies, and internationally-based studies. Studies within each group of sections 2 and 3 will be presented chronologically.

The Metabolic Syndrome

History

The clustering of cardiovascular risk factors was first described in the 1920's when Kylin, a Swedish physician, reported a syndrome marked by hypertension, hyperglycemia, and gout[8]. Two decades later, central adiposity and diabetes were included as risk factors after work by Vague demonstrated a link with cardiovascular disease[9]. It was not until 1977 however, that

Haller and colleagues[10] used the term 'metabolic syndrome' to describe the clustering of five cardiovascular risk factors including: obesity, diabetes, hyperproteinemia, gout, and hepatic steatosis.

The 1988 Banting Lecture, delivered by Reaven, drew the most attention to the clustering of cardiovascular disease risk factors which he termed 'Syndrome X'[11]. Specifically, Reaven discussed the role of insulin resistance and hyperinsulinemia in the etiology of type II diabetes, cardiovascular disease, and hypertension. While Raven's lecture established the clinical importance of Syndrome X, it is important to note that it did not include obesity as a risk factor[11]. Subsequent work by Kaplan[12] termed the clustering of cardiovascular risk factors as the 'deadly quartet,' with others using the name 'insulin resistance syndrome'[13]. However, 'metabolic syndrome' is now recognized as the most appropriate term given the metabolic abnormalities underlying the syndrome.

Common Medical Definitions

Diagnostic criteria for the metabolic syndrome were first proposed in 1998 by the World Health Organization (WHO)[14]. Since this time, several medical societies have proposed their own definitions of the metabolic syndrome including: the European Group for the Study of Insulin Resistance (EGIR), the National Cholesterol Education Program (NCEP)[15], American Heart Association and National Heart Lung and Blood Institute (AHA/NHLBI)[16,17], and the International Diabetes Federation (IDF)[18]. However, the lack of a unified definition became problematic as it led to a variety of prevalence estimates[19] that resulted in confusion amongst clinicians and researchers[20]. Thus, an attempt was made to create a harmonized definition of the metabolic syndrome in 2009. In particular, the Joint Scientific Statement focused on reconciling the differences between the AHA/NHLBI and the IDF definitions (Table 2.1).

Table 2.1: Definitions of the metabolic syndrome.

	AHA/NHLBI 2005	IDF 2005	Joint Scientific Statement 2009
Definition	≥ 3 of 5 components	Central adiposity AND ≥ 2 remaining components	≥ 3 of 5 components
Central Adiposity	WC ≥ 102 cm in men, ≥ 88 cm in women; Asian Americans: ≥ 90 cm in men, ≥ 80 cm in women	Central adiposity: ethnic specific	WC specific to population and country
Triglycerides	≥ 150 mg/dL or pharmacologic treatment	≥ 150 mg/dL or pharmacologic treatment	≥ 150 mg/dL or pharmacologic treatment
HDL-C	< 40 mg/dL in men, < 50 mg/dL in women, or pharmacologic treatment	< 40 mg/dL in men, < 50 mg/dL in women, or pharmacologic treatment	< 40 mg/dL in men, < 50 mg/dL in women, pharmacologic treatment
Blood Pressure	SBP ≥ 130 mmHg, DBP ≥ 85 mmHg, or pharmacologic treatment	SBP ≥ 130 mmHg, DBP ≥ 85 mmHg, or pharmacologic treatment	SBP ≥ 130 mmHg, DBP ≥ 85 mmHg, or pharmacologic treatment
Glucose	fasting plasma glucose ≥ 100 mg/dL or pharmacologic treatment	fasting plasma glucose ≥ 100 mg/dL or type II diabetic	fasting plasma glucose ≥ 100 mg/dL or pharmacologic treatment

AHA, American Heart Association; DBP, diastolic blood pressure; HDL-C, high density lipoprotein-cholesterol; IDF, International Diabetes Federation; NHLBI, National Heart Lung and Blood Institute; SBP, systolic blood pressure; WC, waist circumference.

Table 2.1 summarizes the 2005 AHA/NHLBI and IDF definitions as well as the Joint Scientific Statement put forth by both organizations in 2009. From this table it can be seen that many of the same metabolic syndrome diagnostic criteria of the 2005 AHA/NHLBI and IDF definitions were similar. However, two differences existed between the definitions. First, was that the IDF definition employed ethnic specific cut-points for determining central adiposity. Secondly, the IDF definition required that individuals meet the criteria for central adiposity to be

classified as having the metabolic syndrome. The Joint Scientific Statement[21] resolved the differences between the definitions, using waist circumference cut-points specific to an individual's population and country and removing the requisite condition of central adiposity.

Prevalence

In the U.S. it is estimated that over 65 million people have the metabolic syndrome[1]. At the population level, the prevalence of the metabolic syndrome in the U.S. is typically estimated using data from the NHANES. The first study to estimate the prevalence of the metabolic syndrome using NHANES data was conducted by Ford and colleagues in 2002[22]. Applying the NCEP definition to 1988 – 1994 NHANES III data, the study found that 23.7% of adults met the criteria for the metabolic syndrome[22].

In a follow-up study, Ford et al.[23] used 1988 – 1994 NHANES III data to compare the prevalence of the metabolic syndrome obtained using NCEP and WHO definitions. Results revealed no significant difference in the estimated prevalence between the NCEP and WHO criteria. Specifically, the estimated prevalence of the metabolic syndrome was 23.9% when using the NCEP definition and 25.1% when using the WHO definition[23]. In a subsequent study, Ford compared the prevalence estimates generated using IDF and NCEP criteria[24]. The study, which used 1992 – 2002 NHANES data, found the prevalence of the metabolic syndrome was 39.1% when using the IDF criteria and 34.6% when using the NCEP criteria[24].

More recently, using the 2003 – 2006 NHANES data, Ervin and colleagues[25] and Mozumdar et al.[1] reported the prevalence of the metabolic syndrome in adults to be 34.2% when using the NCEP criteria. Mozumdar and colleagues also found a significant increase of 5% in the prevalence of the metabolic syndrome from the NHANES III to the 1999 - 2006 NHANES[1].

The most recent estimates of the metabolic syndrome in U.S. adults were reported in 2013 by Beltrán-Sánchez and colleagues[26]. In this study the Joint Scientific Statement definition was used to determine the prevalence of the metabolic syndrome in the adult population from the 1999 – 2010 NHANES. The results of this study are inconsistent with previous findings using NHANES data. Specifically, the results of this study indicate a significant, downward trend in the prevalence of the metabolic syndrome from 25.5% in 1999 – 2000 to 22.9% in 2009 – 2010. In addition, this study found no significant trend in the prevalence of the metabolic syndrome for U.S. males (23.7%), while females saw sharp declines from 27.5% to 21.8% between 1999-2000 and 2009 – 2010. While a decrease was seen for the metabolic syndrome as a whole; however, the waist circumference and fasting glucose of U.S. adults significantly increased across the timeframe of the study[26]. The authors suggest that the decline in the metabolic syndrome, triglyceridemia, and attenuated HDL-C seen in this study may be due to their failure to classify adults with dyslipidemia if they were prescribed a lipid lowering medication.

Self-Reported Physical Activity & the Metabolic Syndrome

In the U.S., the association between the metabolic syndrome and self-reported PA has been investigated using a variety of data sources. In particular, self-reported PA data collected as part of the NHANES have been used by researchers to assess the relationship of PA and the metabolic syndrome at the U.S. population level. In a study by Park et al.[27], using data from the 1988 – 1994 NHANES III, the intensities of the most commonly reported leisure time physical activity (LTPA) (*i.e.,* walking, jogging, swimming, gardening/yard work) were used to develop a PA intensity score, which was defined as the ratio of activity-related metabolic rate to resting metabolic rate. A PA intensity score of ≤ 3.5 classified individuals as physically inactive, while moderately active corresponded to a score between 3.6 and 14.9 and active a score of ≥ 15. The

cut-points for moderately active and active were chosen to represent the 15th and 65th percentile of PA for men and 25th and 75th percentile for women, respectively. Results of this study found inactive men had a 40% increased risk for being diagnosed with the metabolic syndrome compared to their active counterparts. However, there was no significant association found for women[27].

In another NHANES III study conducted by Zhu and colleagues[28], the aforementioned PA intensity score was also used to assess the association of self-reported PA with the metabolic syndrome. Results of this study indicated that being physically active was associated with a 31% and 17% reduction in risk of being diagnosed with the metabolic syndrome in men and women, respectively[28]. Similarly, a study conducted by DuBose et al.[29] used self-report PA data from the NHANES III to assess the relationship with the metabolic syndrome. In contrast to the studies by Zhu and Park, this study determined the intensity of self-reported LTPA using the Compendium of Physical Activities; which expresses intensity as metabolic equivalents (METs)[30]. Moderate-intensity PA (MPA) was defined as 3 – 6 METs and vigorous intensity PA (VPA) defined as ≥ 6 METs[30]. Participants were classified as active if they obtained ≥ 5 d/wk of MPA and/or ≥ 3 d/wk of VPA. Participants were classified as irregularly active if they engaged in PA but did not accumulate ≥ 5 d/wk of MPA and/or ≥ 3 d/wk of VPA. Inactive participants were those who reported no LTPA over the past month. Results of this study indicated inactive participants had a 45% increase in the odds of being classified as having the metabolic syndrome[29].

Using data from the 1999-2000 NHANES, Ford et al.[31] examined the relationship between self-reported MVPA, sedentary behavior, and the metabolic syndrome. In this study, MVPA was classified into three categories based on the minutes of activity: 0, < 150, and ≥ 150

min/wk. Sedentary behavior was measured using a question which asked respondents how many hours of television they watched daily over the past 30 days. Results of this study revealed that both MVPA and sedentary behavior were associated with the metabolic syndrome; however there was no interaction between MVPA and sedentary time. Additionally, it was found that individuals who engaged in 0 min/wk of MVPA had almost twice the odds of having the metabolic syndrome compared to those who engaged in 150 min/wk of MVPA[31].

Data from the 1999 – 2004 continuous NHANES was used by Churilla and colleagues[32] to study the relationship between the metabolic syndrome and LTPA using two definitions of the metabolic syndrome developed by the AHA/NHLBI and WHO. Total LTPA was categorized into six levels with the first level comprised of individuals with no self-reported LTPA and the five remaining levels divided into quintiles of LTPA. Results of this study indicated an inverse association between both definitions of the metabolic syndrome and LTPA. Between the two definitions, it was seen that the dose of PA necessary to provide protection against the metabolic syndrome varied. Using the WHO criteria, protection began at the 3rd quintile of PA (393 – 736 $MET \cdot min^{1} \cdot wk^{-1}$), which provided a 30% reduction in risk of the metabolic syndrome. Based on the AHA/NHLBI criteria, significant protection did not begin until the 4th quartile of PA (737 – 1360 $MET \cdot min^{1} \cdot wk^{-1}$), which reduced the risk of the metabolic syndrome by 35%. Additionally, this study found adults meeting the American College of Sports Medicine/AHA PA recommendations for public health were 39 – 46% less likely to have the metabolic syndrome[32]. These results indicate the reduction in metabolic syndrome risk with increased PA varies between metabolic syndrome definitions.

Sisson and colleagues[33] examined the relationship between occupational and domestic PA and the metabolic syndrome in U.S. adults using data from the 2003 – 2006 NHANES. In

this study the AHA/NHLBI definition was used to classify participants as having the metabolic syndrome. Occupational/domestic PA was determined by a question that asked participants to classify their usual daily activities as one of the following: "sit during the day and do not walk about very much, stand or walk about quite a lot during the day but do not have to lift or carry things often, lift or carry light loads or have to climb stairs or hills often, and heavy work or carries heavy loads." Responses indicating activity (*i.e.,* standing, walking, and carrying loads) were collapsed into one category to compare against sitting. Results of this study revealed that compared to individuals reporting occupational/domestic PA, subjects reporting sitting throughout the day were at increased risk for being classified as having the metabolic syndrome. Specifically, men and women were at a 66% and 17% increased risk of being classified as having the metabolic syndrome, respectively. Men and women were also 58% and 40%, respectively, more likely to have a high waist circumference if they spent most of their day sitting[33].

In another NHANES study by Churilla et al.[34], the total volume of PA acquired from leisure-time, domestic, and transportational PA was assessed to determine the association with the metabolic syndrome. Results revealed individuals with higher volumes of total PA and LTPA had significantly lower prevalence of the metabolic syndrome. For both total PA and LTPA, significant protection against the metabolic syndrome was seen starting at the 4th quintile of PA. The volume associated with the 4th quintile, however, was higher for total PA (1261 MET$\cdot$ min$^{1}\cdot$ wk^{-1}) compared to LTPA (736 MET$\cdot$ min$^{1}\cdot$ wk^{-1}). The authors hypothesized the greater volume of total PA necessary for protection was due to the lower intensity of domestic and transportational activities compared to leisure-time activities[34].

In addition to the aforementioned NHANES studies, researchers have used data from a variety of U.S.-based studies to assess the relationship of self-reported PA and the metabolic syndrome. One of these studies is the Bogalusa Heart Study which was used by Gustat and colleagues[35] in 2002 to examine this relationship in a sample of U.S. adults. To assess PA, a questionnaire was used which asked participants to rank their work-related and LTPA on a scale of 1 (inactive) to 5 (very active). Individuals indicating they did not work were excluded from the analysis. Results of this study found moderately to very active individuals (scale 3 – 5) were 44% to 69% less likely to be classified as having the metabolic syndrome compared to their inactive (scale 1) counterparts[35].

The Coronary Artery Risk in Young Adults (CARDIA) study was also used to assess the relationship between PA and the development of the metabolic syndrome[36] in a sample of U.S. adults. The study followed CARDIA participants who were not diagnosed with the metabolic syndrome, from 1985 to 2001. Participants were re-examined six times during the study, with the incidence of the metabolic syndrome determined at baseline, 7, 10, and 15 years using the National Adult Treatment Panel III criteria. The CARDIA Physical Activity History[37] questionnaire was used to assess participation in regular leisure-time and occupational PA. Participant's PA level was classified as low activity, regular activity, or moderate activity. Low activity was defined as having an activity level below the sample's baseline median at all four follow-up examinations. Regular activity was defined as having PA levels above the median of the baseline sample at each of the four follow-up examinations and moderate activity was defined as having PA levels that fluctuated over the course of the study[36].

Results of this study revealed an inverse association between the metabolic syndrome and regular PA[36]. Specifically, regularly active participants were 51% less likely to have the

metabolic syndrome compared to inactive participants, independent of weight gain. After adjustment for smoking and drinking status, dietary measures, and baseline (body mass index) BMI the association was still significant, with regularly active subjects 35% less likely to have the metabolic syndrome[36].

The relationship between PA and the prevalence and incidence of the metabolic syndrome has also been assessed by researchers using data from the Atherosclerosis Risk in Communities (ARIC) Study[38,39]. The ARIC study uses a prospective cohort design to investigate the etiology of cardiovascular disease in Non-Hispanic White and Black adults residing in four U.S. communities. The baseline assessments were conducted from 1987 to 1989 and included 15,792 participants. Follow-up assessments were conducted every three years and LTPA was assessed using a modified version of the Baecke Physical Activity Questionnaire[40]. Using responses to this questionnaire, a LTPA score ranging from 1 (low activity) to 5 (high activity) was calculated for each person. LTPA scores were further classified into one of three tertiles: lowest (1.0 – 2.0), middle (2.25– 2.5), and upper (≥ 2.75). The metabolic syndrome was defined using the NCEP ATP III guidelines.

The first study using ARIC data was published in 2010 by Cheriyath et al.[38] and reported the strength of the association between LTPA and the 6-year incidence of the metabolic syndrome. Results of this study revealed the odds of developing the metabolic syndrome were 20% lower for those in the upper activity tertile compared to the lower activity tertile. The reduced incidence in the upper tertile also remained significant (OR = 0.85; 95% CI: 0.75 – 0.97) after adjusting for demographics, smoking, coronary heart disease, and total cholesterol.

The second ARIC study was published by Bradshaw and colleagues[39] in 2013. This study used all 9-years of ARIC data to determine factors associated with the incidence of the

metabolic syndrome by BMI category (*i.e.,* normal weight, overweight, or obese). This study found the 9-year incidence rate (IR) of the metabolic syndrome was highest for obese individuals (IR: 70.3 per 1,000 person-years), with lower incidence seen in those who were overweight (IR: 37.9 per 1,000 person-years) and normal weight (IR: 15.4 per 1,000 person-years). LTPA was also found to reduce an individual's risk of developing the metabolic syndrome over the 9-year period. Specifically, those in the upper tertile of LTPA were 14% less likely to develop the metabolic syndrome compared to those in the low activity tertile. This association also varied by BMI group, with highly active (*i.e.,* third tertile), normal weight, and overweight individuals experiencing a 29% and 16% reduction in risk for developing the metabolic syndrome compared to their inactive counterparts[39].

In addition to the aforementioned U.S.-based studies, a substantial body of literature exists from researchers across the globe. One such study, the Kuopio Ischemic Heart Disease Risk Factor (KIHD) Study, has tracked a cohort of middle-aged males from Eastern Finland since the 1980's. The study measures a variety of health-related variables including LTPA, which is assessed using the KIHD 12-month Leisure-Time Physical Activity Questionnaire[41]. In a study conducted by Laakenson et al.[42], data from the 4-year follow-up of the KIHD study was used to assess the role of low levels of LTPA with the development of the metabolic syndrome. For the total volume of LTPA, which included all PA intensity sub-categories, logistic regression indicated men accumulating ≥ 487 min/wk of LTPA were 48% less likely to develop the metabolic syndrome compared to those accumulating < 270 min/wk. Looking at the intensity of LTPA, results revealed low-intensity PA was not a significant predictor of the metabolic syndrome. However, accumulating ≥ 18 min/wk of MVPA resulted in a 48% reduction in the risk of the metabolic syndrome. VPA was also associated with reduced risk of developing the

metabolic syndrome. Specifically, accumulating between 10 – 59 min/wk or ≥ 60 min/wk of VPA reduced the risk of the metabolic syndrome by 42% and 68%, respectively[42].

Data from the 1999 – 2000 Australian, Diabetes, Obesity and Lifestyle Study (AusDiab) was used by Dunstan et al.[43] to determine the association between TV viewing and PA with the metabolic syndrome in Australian adults. The analysis included adults > 35 years of age who had complete data for the metabolic syndrome, TV viewing, and PA variables. Individuals were excluded if they were pregnant, had health conditions affecting PA (*i.e.,* diabetes, angina, stroke), or were taking medication for hypertension or dyslipidemia. The Active Australia Survey Questionnaire[44] captured the frequency and duration of participant's PA over the past seven days. Total PA was calculated as the sum of the time spent walking for ≥ 10 min, time spent engaging in other MPA, and two times the duration of VPA in order to create an equivalent MPA volume. Time spent watching TV was classified into three categories: 0 – 7, 7.01 – 14, and > 14 hours/wk. In the study, men and women participating in ≥ 2.5 hours/wk of MVPA were 28% and 47% less likely to be classified as having the metabolic syndrome, respectively. TV viewing, on the other hand, was found to increase the likelihood of having the metabolic syndrome 1.64 and 2.16 times for men and women watching > 14 hours/week of TV, respectively[43].

Data from the Canadian Heart Health Survey (CHHS) was used by Brien and colleagues[45] to examine the relationship between self-reported LTPA and the metabolic syndrome. The CHHS was conducted from 1986 to 1992; utilizing a population-based design to obtain a representative sample of Canadian adults aged 18 – 74 years. In the present study, the metabolic syndrome was defined using NCEP ATP III criteria. Additionally, participants were classified as being physically active if they reported engaging in PA at least once a week for 30

minutes; with individuals falling below this level of PA being classified as inactive. The prevalence of the metabolic syndrome was lower in physically active men (9.4%) and women (7.4%) compared to their inactive counterparts (Inactive: Men: 22.1%; Women: 13.0%). In addition, physically active participants were 27% less likely to have the metabolic syndrome compared to inactive individuals. When examined by gender, a significant reduction in risk was only seen in physically active males [OR: 0.45 (95% CI: 0.29 – 0.69)]. The authors indicate the lack of differentiation in PA levels and information on menopause status may have contributed to the gender differences.

In Norway, the Oslo Study has allowed researchers to determine the influence of LTPA on the development of the metabolic syndrome in older men[46]. The study was comprised of Oslo men born between 1923 and 1932. Baseline samples were taken in 1972 – 1973 with a follow-up conducted 28 years later in 2000 – 2001. Results from the Oslo study indicated males accumulating four hours or more per week of LTPA at baseline were 35% less likely to be diagnosed with the metabolic syndrome at follow-up, after adjustment for age and education[46].

The association between the metabolic syndrome and PA was examined in Korean adults by Cho et al.[47]. The study sample was comprised of 14,531 Korean men and women who completed a cancer screening at the Center for Cancer Prevention and Detection of the National Cancer Center in South Korea between 2002 and 2007. After excluding those under the age of 30 years and individuals with missing data, the final sample size was 11,925. Based on participant's responses to a self-report questionnaire, total LTPA was calculated as MET·min/wk. Results of this study revealed a reduction in the risk of the metabolic syndrome occurred for Korean men and women accumulating over 990 and 945 MET·min/wk, respectively. Specifically, Korean men were 16% less likely to have the metabolic syndrome if

they accumulated 990 – 1515 MET·min/wk of PA, with those accumulating over 1515 MET·min/wk having a 25% reduction in risk. Women engaging in 945– 1440 MET·min/wk of PA were 46% less likely to have the metabolic syndrome, with those accumulating over 1440 MET·min/wk having a 35% reduction in risk. The authors did not discuss why increased volume of PA did not result in a greater reduction in metabolic syndrome risk for women[47].

In a recent study, the Joint Interim Statement definition was used to classify participants from the 2005 – 2008 Tehran Lipid and Glucose Study[48]. Using participant's responses to the Modifiable Activity Questionnaire[49,50], LTPA was categorized as light (< 600 MET·min/wk), moderate (600 – 1499 MET·min/wk), and vigorous (≥ 1500 MET·min/wk). Results indicated that there was no association between PA and the metabolic syndrome for normal weight and obese Iranian adults. However, overweight Iranians with low levels of PA (*i.e.,* < 600 MET·min/wk) were found to have twice the risk for being classified as having the metabolic syndrome than Iranians accumulating ≥ 1500 MET·min/wk of PA. The authors suggest that these results may be due in part to the use of the Joint Scientific Statement metabolic syndrome criteria and the limited number of participants in various activity and BMI categories[48].

Summary of Self-Report Physical Activity & the Metabolic Syndrome

Of the 17 studies reviewed, a consistent inverse association was found between higher levels of self-reported PA and the metabolic syndrome. Across studies, physically active individuals were 14% to 69% less likely to have the metabolic syndrome compared to their inactive counterparts. The observed range in risk reduction across studies may be related to variations in study design, study population, and the self-report PA measures used. Consistent with the *2008 Physical Activity Guidelines*[51], the studies reviewed found a significant reduction in metabolic syndrome risk among individuals accumulating ≥ 150 min·wk of MVPA.

While these studies consistently displayed a relationship between self-reported PA and the metabolic syndrome, there are several limitations that should be considered. In particular, due to the cross-sectional design of many studies, causality could not be determined. Also, many of the studies lacked the PA measures necessary to calculate the total PA volume including: intensity, frequency, duration, and mode of PA. The accurate calculation of total PA volume was also limited in many studies by the use of a questionnaire that only assessed LTPA.

Objectively-Measured Physical Activity & the Metabolic Syndrome

Although the relationship between metabolic syndrome and PA has been demonstrated using self-report methods of PA, self-report measures are subject to substantial bias that has been well documented in the PA Epidemiology literature[52-55]. In contrast, objective measures of PA, such as accelerometers, may provide increased precision and decreased bias when investigating the dose-response relationship and potential threshold effect associated with the metabolic syndrome. However, there are a limited number of studies using accelerometers to assess the relationship between the metabolic syndrome and PA[56-58]. Additionally, these studies use different accelerometer-derived measures of PA; limiting the interpretability of results across studies.

The variation in accelerometer-derived measures has been seen in U.S.-based studies utilizing NHANES accelerometer data. For example, Metzger and colleagues[57] explored whether MVPA performed in 1-minute bouts and accumulated in different patterns across the week (*e.g.,* weekend warrior, consistent accumulation across the week, etc.) was associated with the metabolic syndrome. Using data from the 2003 – 2004 NHANES, a SEM was proposed and subsequently tested in order to determine associations between the pattern of MVPA accumulation (*i.e.,* how PA was accumulated throughout the week), risk factors of the metabolic

syndrome, and classification of the metabolic syndrome in U.S. adults. In this study, MVPA was classified as the average daily minutes with counts at or above 2020. The NCEP[15] criteria were used to classify adults as having the metabolic syndrome. Results of the study revealed that individuals accumulating the weekly recommended amount of PA had a lower risk of developing the metabolic syndrome. However, no difference in the risk of the metabolic syndrome was seen when examining the pattern in which MVPA was accumulated throughout the week [57].

In another study, Sisson et al.[58] used 2005 – 2006 NHANES data to determine the association of accelerometer-derived steps/day and the odds of having the metabolic syndrome in U.S. adults. The AHA/NHLBI[17] criteria were used to classify participants as having the metabolic syndrome. Results of this study indicated for every 1,000 steps/day accumulated the odds of having the metabolic syndrome decreased by 10%. In addition, active to highly active individuals (≥10,000 steps/day) had 72% lower odds of the metabolic syndrome compared to their sedentary counterparts[58].

Accelerometer-based measures of PA were also used by Jansen et al.[56] to investigate the relationship with the metabolic syndrome. Using the 2003 – 2006 NHANES, the association between the metabolic syndrome and accelerometer-derived minutes of MPA, VPA, and MVPA performed in 1-minute bouts was examined. The intensity of activity was first determined using the Freedson[3] regression equation, which estimated the METs from the counts/minute obtained from the accelerometer. MET thresholds, consistent with the Compendium of Physical Activity[30], were then used to classify the intensity of PA. Results of this study revealed that the odds of the metabolic syndrome decreased with increasing levels of MPA, VPA, and MVPA. Independent associations of VPA and MPA with the metabolic syndrome were also found. It was also found that approximately 75 minutes/week of VPA provided a greater reduction

(37.1%) in the prevalence of the metabolic syndrome than an equivalent volume (150 minutes/week) of MPA (15.5%)[56].

The effects of both LPA and MVPA on metabolic syndrome risk were also highlighted by Loprinzi and colleagues[59]. Their study used the 2003 – 2006 NHANES data and classified individuals as having the metabolic syndrome based on AHA/NHLBI criteria. MVPA was classified as the average number of minutes with counts above ≥ 2020 and LPA was defined as minutes with counts between 100 and 2019. Minutes of MVPA and LPA were then categorized into deciles in order to examine the dose-response relationship with the metabolic syndrome. Results of the study indicated individuals with the highest levels of LPA and the highest levels of MVPA were least likely to be classified as having the metabolic syndrome. Specifically, individuals in the 9th decile for LPA and 10th decile for MVPA were 45% and 80% less likely to be classified as having the metabolic syndrome compared to those in the 1st decile, respectively[59].

In another NHANES study by Loprinzi et al.[60], the association of the metabolic syndrome and related risk factors with PA accumulated in ≥ 10-min and < 10-min bouts was examined. The authors of this study used the 2003 – 2006 NHANES data and defined PA with the commonly used cut-point for MVPA of 2020 counts/min. Results of this study revealed both bouted and non-bouted MVPA significantly reduced the risk of the metabolic syndrome and related cardiometabolic risk factors. Non-bouted MVPA was also found to protect against classification of the metabolic syndrome after adjusting for bouted MVPA (OR: 1.02; $p = 0.006$), suggesting non-bouted MVPA may provide benefits for cardiometabolic health[60].

In addition to U.S.-based NHANES studies, a variety of internationally-based studies have examined the relationship between the metabolic syndrome and accelerometer-derived PA.

In particular, data from the 2005 AusDiab Study was used by Healy al.[61] (2008) to examine the associations between the percent of time spent in various accelerometer-derived intensities of PA and the metabolic syndrome. Sedentary time was defined as minutes with < 100 counts[62] and LPA was defined as minutes between 100 – 1951 counts. Freedson[3] cut-points were also used to determine MVPA (≥ 1952 counts/min). The percentage of time spent in each intensity level was calculated using the number of minutes at the intensity level as the numerator and the total monitoring time (*i.e.,* wear time) as the denominator. The mean activity intensity was also calculated and represented the total counts accumulated over the total monitoring time.

Instead of using accepted medical society criteria to classify individuals as having the metabolic syndrome, a continuous metabolic syndrome risk score was computed using principal component analysis. Specifically, a varimax rotation principal component analysis was applied to normalized risk factors of the metabolic syndrome, using IDF criteria[18], for men and women separately. The risk factor loadings from the principle component analysis were then summed and weighted to account for their relative influence on the metabolic syndrome; producing the continuous metabolic syndrome risk score. Results of this study revealed a significant association with the clustered metabolic syndrome risk score was found for all PA variables. After adjusting for MVPA, the associations of sedentary time [ß = 0.23 (95% CI: 0.08 – 0.38)], LPA [ß = –0.23 (95% CI: –0.35 to –0.04)] and mean activity intensity [ß = –0.25 (95% CI: -0.41 to –0.09)] with the clustered metabolic syndrome risk score remained statistically significant[61].

In a prospective study conducted by Park et al.[63] (2008), the relationship between habitual PA and the metabolic syndrome was assessed in older adults. Using accelerometer/pedometer data from the Nakanojo study, 1-year averages for step counts and daily duration of exercise > 3 METs was calculated. Results of this study indicated older adults accumulating < 4700

steps/day were 4.32 more likely to have the metabolic syndrome than individuals accumulating > 8,500 steps/day. Additionally, older adults accumulating ≤ 8.5 min/day of PA above 3 METs were 3.33 times more likely to have the metabolic syndrome than those engaging in over 24 min/day[63].

The influence of very short bouts of MVPA (< 5 minutes) on the metabolic syndrome was examined in 2012 by Ayabe and colleagues[64]. The sample consisted of 42 Japanese females between 40 – 60 years of age who were free of chronic disease. A Lifecorder-Ex accelerometer measured participant's PA over a 10 day period. Participants were excluded from the analysis if they did not wear the accelerometer for more than 10 hours on at least seven days. The following bout lengths were used to classify time spent in MVPA: > 32 s, > 1 min, > 3 min, and > 5 min. Results revealed the frequency of 1-minute bouts of MVPA were significantly greater in females without the metabolic syndrome compared to those classified as having the metabolic syndrome (6.2 ± 3.8 vs. 3.4 ± 2.5 bouts/day, $p = 0.043$). The frequency of all other bout lengths, however, was not found to be statistically different between those classified with and without the metabolic syndrome[64].

In a study by Kim al.[65], the association of accelerometer-derived LPA with the metabolic syndrome was examined in Japanese adults. A tri-axial accelerometer (Omron HJA-350IT, Active Style Pro) was used to assess PA. The intensity of PA was classified as sedentary (≤ 1.5 METs), LPA (1.6 – 2.9 METs), and MVPA (≥ 3 METs). A significant, negative association was found between LPA and the frequency of the metabolic syndrome ($p_{trend} = 0.001$). In addition, it was found that individuals with higher LPA were at lower risk for the metabolic syndrome, independent of MVPA. Specifically, individuals accumulating 11.2 – 14.5 or ≥ 14.6

MET·hr/day of LPA were 49% and 56% less likely to have the metabolic syndrome, respectively[65].

Data from the 2007 – 2011 Canadian Health Measures Survey (CHMS) was used by Clarke and Janssen[66] to examine the relationship between the frequency of MVPA and the metabolic syndrome in Canadian adults. In the study, the metabolic syndrome was defined using the Joint Interim Statement criteria. PA was assessed using an Actical accelerometer. A regression equation was used to calculate the energy expenditure (METs) of time spent in MVPA (*i.e.,* minutes with ≥1535 counts). MVPA was also classified as minutes accumulated in bouts of 10 minutes or more with sporadic MVPA defined as bouts of < 9 min. Participants were also classified into the following three groups based on their total MVPA (bouted + sporadic MVPA) and bouted MVPA: 1) inactive (< 250 MET·min/wk), 2) somewhat active (250 - 499 MET·min/wk), and 3) active (≥ 500 MET·min/wk). The results for bouted MVPA revealed the risk of being classified with the metabolic syndrome was 3.1 times higher in the inactive group compared to the active group. When examining total MVPA, individuals in the somewhat active and inactive groups were at 3.34 and 4.43 greater risk of being classified with the metabolic syndrome than those in the active group[66].

In another study by Clarke and Janssen[67], 2007 – 2009 CHMS data was used to examine whether bouted MVPA or sporadic MVPA was more strongly related to the metabolic syndrome. The study utilized the same definitions for the metabolic syndrome and MVPA as the aforementioned CHMS study. Independent associations of bouted MVPA and sporadic MVPA with the metabolic syndrome were found to be similar. Specifically, each additional MET·hr/wk of bouted MVPA and sporadic MVPA was associated with a 9% and 11% reduction in the risk of the metabolic syndrome. The association of different durations of sporadic MVPA (*e.g.,* 7 –

9, 4 – 9, and 1 – 9 minutes) with the metabolic syndrome was also examined. Results revealed that sporadic MVPA accumulated in one to nine minute bouts was the best fitting model for predicting the metabolic syndrome (Akaike Weight %: 95.86); indicating MVPA accumulated in one to three minute bouts may reduce the risk of the metabolic syndrome[67].

Summary of Objectively-Measured Physical Activity & the Metabolic Syndrome

Of 13 studies reviewed, a consistent inverse association was found between higher levels of accelerometer-derived PA and the metabolic syndrome. In particular, physically active individuals were 15.5% to 80% less likely to have the metabolic syndrome compared to inactive individuals. The range in risk reduction between these studies may be related to variations in study design, study population, the accelerometer used, and the accelerometer-derived PA intensity of volume measure used. Results of these studies also highlight the importance of all intensity sub-categories of PA. Specifically, a significant reduction in metabolic syndrome risk was found with increased levels of LPA, non-bout MVPA, and bouted MVPA.

However, there are several limitations of these studies. First, the cross-sectional design of these studies prevents researchers from determining causality. Second, the variety of activity monitors and accelerometer-derived PA measures used in these studies limits researchers from drawing comparisons across studies. In addition, many of these studies utilized hip-worn, uni-axial accelerometers which may have failed to capture non-ambulatory activity including cycling, weight training, and swimming.

Accelerometer Data Reduction Techniques

Over the past two decades, the use of objective monitors in research has increased exponentially[68]. While accelerometers have gained acceptance within the research community, there is concern that accelerometers may not provide quantitatively accurate measurements of

time spent in various intensity categories (*i.e.,* sedentary, light, moderate, and vigorous). The following section will discuss the use of regression equations, and address concerns associated with classifying intensity using cut-points derived from this technique. This section will also discuss the use of an accelerometer-derived total volume measure as an alternative to traditional accelerometer data reduction techniques.

Regression Equations

Regression equations have been developed by researchers in order to translate the counts obtained from an accelerometer into energy expenditure which is used to estimate the time spent in various intensities of activity. The first regression equation was developed by Freedson et al.[3] in 1998 for the Computer Science Applications (CSA) accelerometer. The Freedson equation determined the intensity of activity based on counts accumulated at three different walking speeds (4.8, 6.4, and 9.7 km/hr). Based on the regression equation, cut-points were developed which corresponded to light (<1952 counts per minute (cpm)), moderate (1952 – 5724 cpm), hard (5725 – 9498 cpm), and very hard intensity ($\geq$ 9499 cpm)[3].

During this time, Hendelman et al.[69] were also interested in the relationship between accelerometer counts and energy expenditure. However, the focus of Hendelman's work was on developing equations for the CSA accelerometer and Tritrac monitor that were based on moderate-intensity lifestyle activities (*i.e.,* playing golf, household tasks, washing windows, vacuuming, lawn mowing). Using all activities, the following equations were developed to calculate MET values from the devices counts per minute: [$METs_{CSA} = 2.922 + 0.000409*CPM_{CSA}$] and [$METs_{Tritrac} = 2.817 + 0.0011*CPM_{Tritrac}$][69].

In 2000, Bassett and colleagues[70] conducted a study to compare the accuracy of the Freedson[3], Hendelman[69], and CSA manual[71] (work-energy theorem) equations. Participants in

the study completed activities related to yard work, housework, occupation, family case, conditioning, and recreation. During the activities, which lasted 15 minutes each, oxygen consumption (VO_2) was measured using the Cosmed K4b^2 portable indirect calorimetry system and the CSA (model 7164) accelerometer was worn on the participant's waist. After data collection, the equation specific algorithms were applied to the accelerometer outputs and correlations were calculated to compare the equations and indirect calorimetry outputs. Results revealed the estimated energy expenditure derived from the Hendelman ($r = 0.62$) and CSA manual ($r = 0.62$) equations had the strongest relationship with the actual energy expenditure (*i.e.,* indirect calorimetry). However, both accelerometer equations were found to underestimate the intensity of the activities by 30.5 – 56.8%. The largest difference was seen for household activities, as the accelerometer equations underestimated four of the five activities by over 50%[70].

These results are consistent with other studies which have found that accelerometer-derived estimates of time spent in various PA intensity categories do not correspond with measurements obtained by indirect calorimetry[6,7]. For example, one study found the total amount of time spent in MVPA, regardless of bout duration, was underestimated by 50% when using NHANES ActiGraph cut-points[6]. In another study, Lyden et. al[72] evaluated the ability of different regression equations for the ActiGraph, Actical, and RT_3 accelerometers to accurately classify time spent in PA intensity sub-categories. Results of this study found that none of the regression equations examined were able to correctly classify minutes spent in each intensity category, with the misclassification error ranging from 8.9 - 34.3% for MPA and 28.2 - 54.5% for VPA. The authors note that the misclassification error of MPA may be related to the insensitivity of the regression equations to distinguish LPA due to the high y-intercept of 2.6

METs. While regression equations with a lower y-intercept had increased sensitivity to LPA, they tended to underestimate MPA and VPA[72].

Due to this misclassification error, the PA estimates derived from cut-points vary widely. This was demonstrated by Loprinzi et al., using the NHANES data, who found the time spent in MVPA ranged from 17 to 59 minutes per day and the percentage meeting PA guidelines ranged from 6.2 – 59.3%, depending on the regression equation used[73]. Therefore, it is unclear which cut-point(s), if any, provide an accurate representation of the time spent in LPA, MPA, and VPA. This is important as the misclassification error may affect the relationship with disease, leading to conflicting results. In addition to the estimation error associated with accelerometer algorithms, the numerous cut-points also hinders the ability to draw comparisons between studies[74,75]. Thus, Freedson et al.[75] have therefore urged researchers to discontinue the development of cut-points to categorize accelerometer-derived PA.

Total Volume

One way to circumvent the issues with other accelerometer data reduction techniques is to use the total activity counts (TAC) output by the device. TAC may be a better measure of PA as it is the most direct expression of what the accelerometer measures. It is also a proxy for total volume of PA as it encompasses the frequency, intensity, and duration of activity.

In addition, recent evidence suggests that LPA, MPA, and VPA all have health benefits. This is reflected in work by Healy et al.[76] which showed that individuals who perform greater amounts of LPA have a reduced incidence of diabetes. Kim et al.[65] also found that individuals with higher levels of LPA were at lower risk for the metabolic syndrome, independent of MVPA. Furthermore, research related to sedentary behavior has indicated that LPA is highly inversely correlated with sedentary time (r = - 0.98) after adjusting for wear time[77]. In addition to LPA,

recent evidence suggests that MVPA accumulated in short, intermittent bouts may provide similar or additional benefits for cardiovascular and metabolic health, as MVPA accumulated in bouts of 10 minutes or longer[67,78,79]. The effects of both LPA and MVPA were highlighted by Loprinzi et al.[59] who found individuals with the highest levels of both LPA and non-bout MVPA were least likely to be classified as having the metabolic syndrome. Taken together, these studies suggest that LPA and intermittent (non-bout) MVPA have health benefits and should be accounted for.

Recently the importance of a global, objective measure of PA such as TAC was explored by Wolff and colleagues (Part IV and V). The first study, which utilized accelerometer data obtained from the 2003 – 2006 NHANES, demonstrated that TAC had stronger associations with cardiometabolic biomarkers (*e.g.*, blood pressure, body mass index, and cholesterol) than traditional accelerometer-derived minutes spent in MVPA bouts of 10 minutes or greater (Part IV). Five cardiometabolic risk factors comprising the metabolic syndrome were found to be more strongly related to TAC than MVPA: waist circumference, fasting glucose, triglycerides, HDL-C, and systolic blood pressure. One risk factor, diastolic blood pressure, was not found to have significant associations with either TAC or MVPA. These results suggest that TAC is a more robust measure of PA, as it is more closely related to health indicators associated with the metabolic syndrome (Part IV).

In the second study conducted by Wolff and colleagues (Part V), age- and gender-specific population-referenced percentiles for TAC, MVPA, and LPA were developed. The population-reference values provide researchers with a measure of the total volume of PA that can be expressed relative to other adults (*i.e.,* as percentiles). Additionally, this is a different

approach to accelerometer data reduction that complements the current method of looking at time spent in intensity sub-categories.

Despite the aforementioned results highlighting the benefit of a total volume measure of PA, future research is necessary to explore the relationships of TAC with various health indicators. In particular, it is necessary to determine whether TAC or another accelerometer-derived PA measure has the greatest contribution to chronic disease risk reduction. Statistically, the relative contribution of each PA measure in the reduction of disease risk can be determined using SEM. The following section describes this advanced statistical technique and its use in Physical Activity Epidemiology.

Structural Equation Modeling

Over the past two decades, SEM has gained popularity in the social and behavior sciences[80]. Within the field of Physical Activity Epidemiology, SEM provides a novel tool that gives researchers the opportunity to examine multiple disease risk factors and health behaviors (*e.g.,* PA) simultaneously. Also, SEM enables researchers to include correlated measures, through the use of latent constructs. This is particularly important when examining the role of multiple intensity levels of PA, which are highly correlated. The following section provides a brief introduction to SEM and discusses its use in NHANES studies assessing the relationship of PA with various chronic diseases.

Structural equation modeling (SEM) is an advanced statistical technique which tests hypotheses about the relationships between observed (manifest) variables and latent constructs[81]. Latent constructs are comprised of multiple measures that are classified as being exogenous or endogenous. Exogenous constructs are not dependent on any other variables and are therefore thought of as the independent variables. Endogenous constructs are considered mediating or

dependent variables as these constructs are dependent on at least one other construct. A structural equation model contains the relationship between exogenous and endogenous latent constructs, the loadings of manifest variables onto each construct, and measurement and prediction error[81-83].

There are several advantages of SEM compared to other multivariate statistical approaches. In particular, SEM uses multiple measures to define a construct and it yields unbiased parameter estimates. SEM enables researchers to examine both direct and indirect effects (*i.e.,* moderating and mediating variables) simultaneously. Additionally, SEM allows for the comparison of multiple theoretical models which are well-specified and complex[81,84].

SEM gives researchers statistical flexibility to analyze both simple and complex models. Specifically, SEM can be used to analyze longitudinal and cross-sectional data. It can also be used to analyze dependent observations such as family data[80,81]. SEM also fits the raw data instead of using summary statistics, reducing the problems associated with missing observations. Furthermore, this technique is not limited by the measurement level of the variable as it manages interval and categorical data simultaneously[80,81,83].

The ability of SEM to simultaneously determine the mediating and moderating effects of multiple health behaviors on chronic diseases makes it an ideal tool for analyzing data from the NHANES. To our knowledge, however, only two studies have applied SEM to the NHANES data. The first study by Metzger and colleagues[57] examined whether the pattern by which accelerometer-derived MVPA is accumulated during the week is associated with the metabolic syndrome. The MVPA accumulated by participants on each day of the week was classified into one of five groups, indicating a specific pattern of PA accumulation (*i.e.,* weekend warrior, occupational-related accumulation, consistent accumulation). Results of the study revealed that

individuals accumulating the weekly recommended amount of PA had lower risk of developing the metabolic syndrome. However, no differences in metabolic syndrome risk were seen when examining the pattern in which MVPA was accumulated throughout the week[57].

The second NHANES study using SEM was conducted by Bardenheier and colleagues[85], who examined factors associated with pre-diabetes in older adults. This study utilized 2001 – 2006 NHANES data and classified individuals as pre-diabetic if they had a fasting glucose ≥ 126 mg/dL or $HbA_{1c} \geq 6.5\%$. Several measures of PA, obtained from questionnaire, were used to define the PA construct including: $MET \cdot hr \cdot wk^{-1}$ of MPA and VPA, minutes of walking/biking, muscle strengthening exercise, and house/yard work. Results of this study revealed the best fitting model was one which included causal paths of socioeconomic status, poor diet, and PA on pre-diabetes. However, the causal pathway between PA and pre-diabetes was not significant. Instead, the PA construct was found to have a direct effect on HDL-C (0.137), triglycerides (-0.136), high blood pressure (-0.132), and high waist circumference (-0.067)[85].

In summary, SEM is a powerful, multivariate statistical tool. While the use of SEM has grown in many fields, within Physical Activity Epidemiology SEM remains a novel approach to understanding the complex relationship of health behaviors and chronic disease risk. Therefore, future studies exploring the inter-relationships of health behavior and chronic disease should consider utilizing SEM.

Summary

In the United States, the current prevalence of the metabolic syndrome ranges from 22.9[26] to 32.4%[1,25;] with older individuals and males having the highest prevalence estimates. The almost 10% variation in the prevalence is most likely due to the medical society definitions of the metabolic syndrome applied to the study populations. While the 2009 Joint Interim

Statement[21] attempted to create a unified definition of the metabolic syndrome, there have been few studies that have applied this definition. This may be due in part to the similarities of the Joint Statement[21] with the more commonly used AHA/NHLBI[16,17] definition.

For both self-report and accelerometer-based PA, a consistent inverse association was found between the metabolic syndrome and higher levels of PA. However, the variety of self-report and accelerometer-derived measures used in these studies makes it difficult to determine the minimum dose of PA associated with a reduced risk of the metabolic syndrome. In addition, while a reduced risk in the metabolic syndrome was seen with increased volume of PA, the total PA volume measures were limited by the domains they captured via self-report or the sub-intensity level that was assessed via accelerometer.

Despite these limitations, the results of these studies provided substantial evidence for the use of a total volume measure of PA derived from accelerometers. In particular, accelerometer-derived minutes of LPA, non-bout MVPA, and bouted MVPA were associated with a significant reduction in metabolic syndrome risk. Furthermore, pilot work (Part IV) has demonstrated that total activity counts, an indicator of the total volume of PA, is more strongly associated with cardiometabolic biomarkers than MVPA performed in 10 minute bouts (Part IV). In light of these results, future research is necessary to determine the role of PA intensity in the development of the metabolic syndrome.

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PART III

METHODOLOGY

The purpose of this study, presented in Part VI, was to determine whether accelerometer-derived TAC, MVPA, or LPA provided the best fit for assessing the relationship with the metabolic syndrome. This study also assessed the relative contribution of LPA, MPA, VPA, and TAC to the reduction in the prevalence of the metabolic syndrome. This study utilized cross-sectional data from the 2003 –2006 National Health and Nutrition Examination Survey (NHANES). The following section describes the measures and analyses that were utilized in this study.

Subjects

For this study, the sample was limited to adults ≥ 20 years of age who participated in a fasting morning examination ($N = 4312$). Participants with less than four days of ≥ 10 hours of accelerometer wear time ($n = 1513$), pregnant or lactating women ($n = 146$), and individuals with missing data ($n = 415$) were excluded from the analyses, resulting in a final sample of ($n = 2238$). The original survey protocols were approved by National Center for Health Statistics ethics review board, and informed consent was obtained from all NHANES participants. The University of Tennessee institutional review board approved the use of NHANES data in this analysis.

Data Collection

The present study used data from the 2003 – 2006 National Health and Nutrition Examination Survey (NHANES). The NHANES is a cross-sectional survey utilizing a complex, multistage probability design in order to obtain a representative sample of the non-institutionalized United States (U.S.) population[1]. The NHANES data are collected during an in-person home interview and a visit to a mobile examination center (MEC). The interview collects

demographic, socioeconomic, and health-related information. The examination consists of laboratory tests and medical and physiological measurements.

All ambulatory individuals examined in the MEC were eligible participants for the accelerometer component. Eligible participants were instructed to wear an ActiGraph model 7164 accelerometer for seven days on their right hip during waking hours, and to take it off for swimming or bathing[2]. Details of the accelerometer protocol can be found on the Centers for Disease Control and Prevention (CDC) website[3].

Study Measures

The 2003 – 2006 NHANES required extensive recoding and data management to create the measures used in this study. A description of these measures is presented below.

Dependent measure: The Metabolic Syndrome

The dependent variables were cardiometabolic risk factors of the metabolic syndrome based on criteria established by the American Heart Association and National Heart, Lung, and Blood Institute (AHA/NHLBI)[4]. The AHA/NHLBI definition was selected over other definitions of the metabolic syndrome as it is the most appropriate criteria for the U.S. population based on the joint scientific statement of the International Diabetes Federation and the AHA/NHLBI[5]. The AHA/NHLBI definition of the metabolic syndrome is unique in that no specific condition is required (*i.e.,* obesity, insulin resistance) for diagnosis. Instead this definition requires an individual display any three of the five risk factors for a positive diagnosis of the metabolic syndrome. The five metabolic syndrome criteria defined by the AHA/NHLBI include[4]:

1. Central adiposity defined as a waist circumference > 102 centimeters (cm) in men and > 88 cm in women;

2. Elevated triglycerides ≥ 150 milligrams per deciliter (mg/dL) or undergoing pharmacological treatment;
3. Attenuated high-density lipoprotein cholesterol (HDL-C) defined as < 40 mg/dL in men and < 50 mg/dL in women, or undergoing pharmacological treatment;
4. Elevated blood pressure ≥ 130 / ≥ 85 mmHg, or undergoing pharmacological treatment; and,
5. Impaired fasting glucose ≥ 100 mg/dL or undergoing pharmacological treatment.

Using the AHA/NHLBI definition of the metabolic syndrome, measures of waist circumference, lipoprotein concentrations, blood pressure, and fasting glucose were obtained using data from the MEC component of the NHANES survey. Details of the laboratory methods can be found on the Centers for Disease Control and Prevention (CDC) website[6]. To determine whether a component of the metabolic syndrome meet inclusion criteria, each risk factor was dichotomized using the cut-off values and pharmacological treatment criteria (0 = does not meet criteria; 1 = meets criteria). In addition, individuals were classified as having the metabolic syndrome if they displayed three or more of the five aforementioned risk factors. The recoding of the metabolic syndrome variable and the five risk factors as dichotomized variables (0 = does not meet criteria, and 1 = meets criteria) provides an estimate of the prevalence for each variable.

Independent measures

A variety of independent variables were assessed in this study. The primary independent variables were average daily accelerometer-derived physical activity (PA) measures. Depending on the model, the following four PA measures were used: average daily minutes of light- (LPA), moderate- (MPA), or vigorous intensity PA (VPA) and total activity counts per day (TAC). All

other variables served as covariates for both studies. The following section describes each independent variable in further detail.

Objectively measured physical activity

The NHANES accelerometer data were collected in one-minute epochs using an ActiGraph model 7164, which is a uniaxial accelerometer measuring vertical acceleration. In this study, accelerometer data was analyzed using the SAS macro provided by the National Cancer Institute[7]. Non-wear time was defined as ≥ 60 consecutive minutes with zero accelerometer counts, allowing up to two minutes with limited movement (< 100 counts/minute). Daily wear time was determined by subtracting non-wear time from 24 hours. A valid day was defined as a day with 10 or more hours of monitor wear[8]. Only participants with at least four days of valid monitor wear time were eligible to be included in this analysis.

- Total Activity Counts per day (TAC): The variable total activity counts per day (TAC) was created by summing the counts accumulated on each valid day. As TAC captured all counts accumulated during valid wear times it therefore included time spent in sedentary activity and all PA intensity sub-categories.
- Light Physical Activity (LPA): Using thresholds described by Troiano[2], LPA was defined as the total number of minutes with 100 – 2019 counts per minute.
- Moderate Physical Activity (MPA): Using thresholds described by Troiano[2], MPA was defined as the total number of minutes with 2020 – 5998 counts per minute.
- Vigorous Physical Activity (VPA): Using thresholds described by Troiano[2], VPA was defined as the total number of minutes with ≥ 5999 counts per minute.

All PA metrics were averaged across the number of valid days to provide an average of the total minutes or counts accumulated daily.

Covariates

Several confounding variables served as covariates in this study, including four demographic variables: age, race/ethnicity, education, and income level. Additionally, one variable assessing family history of disease was included as a covariate.

- Age: Age, measured in years, was categorized into the following six categories: 20 – 29, 30 – 39, 40 – 49, 50 – 59, 60 – 69, and ≥ 70 years of age.
- Race/Ethnicity: Participants were classified into one of three race/ethnicity groups. The four categories were the following: Non-Hispanic White, Non-Hispanic Black, and Mexican American/Other.
- Education: A five level variable was used to classify participant's education level: less than 9^{th} grade, 9 – 11^{th} grade, HS graduate or General Educational Development (GED) diploma, some college or Associates of Arts degree, and college graduate or greater.
- Income: Participants were classified into one of eight categories based on their self-reported annual household income. The eight categories, in thousand (K) dollar units were : <$20K, $20 – 24.9K, $25 – 34.9K, $35 – 44.9K, $45 – 54.9K, $55 – 64.9K, $65 – 74.9K, and ≥ 75K.
- Family History of Coronary Heart Disease: The AHA/NHLBI recognizes that a family history of coronary heart disease increases an individual's risk of the metabolic syndrome[4]. Participants were classified as having a family history of coronary heart disease if they reported a parent and/or sibling had the condition. The variable was dichotomized with one category indicating family history and the other reflecting no family history.

Statistical Analysis: Structural Equation Modeling

The 2003 – 2006 NHANES data used in this study were downloaded from the demographics, examination, laboratory, and questionnaire sections of the CDC website[3]. All recodes were performed using SAS 9.2 (SAS Institute, Inc., Cary, NC). In addition, the SAS macro provided by the National Cancer Institute[7] was used to recode accelerometer-derived measures of PA. Descriptive analyses (*i.e.,* Chi-square tests and independent-samples T-tests) were also performed using SAS 9.2. These analyses did not account for the complex sampling design of the NHANES in order to make comparisons to the results obtained from the structural equation modeling (SEM) analyses.

Specifically, SEM was performed using AMOS 20.0 (AMOS Development Corp., Meadville, PA), which is unable to take into account the NHANES sampling weights and sampling design variables which account for complex sampling design. In the present analysis, three hypothetical models were tested using SEM. The three models were stratified by gender and used various accelerometer-derived measures of PA to examine the association between the prevalence of the metabolic syndrome, the prevalence of the five components of the metabolic syndrome, and accelerometer-derived PA. The dependent variable in these models was prevalence of the metabolic syndrome, which had five manifest variables (*e.g.,* waist circumference, blood pressure). The independent variable, accelerometer-derived PA, was measured continuously, with each model including different intensity sub-categories. In model 1, the PA construct was comprised of two manifest variables: accelerometer-derived MPA and VPA. Model 2 had three manifest variables (LPA, MPA, and VPA) loading onto the PA construct. For model 3, TAC was the only manifest variable loading onto the PA construct.

Maximum likelihood (ML) estimation was used to estimate model parameters. This estimation method is the most commonly used procedure in SEM as it is robust against moderate non-normality[9]. The fit of each model was also compared to determine which accelerometer model best explained the reduction in the prevalence of the metabolic syndrome associated with PA. This analysis evaluated four different fit indices: chi-square (χ^2) to degrees of freedom (df) ratio (χ^2/df), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Akaike Information Criterion (AIC). The χ^2/df ratio assesses the fit of a model and the data, with ratios < 4 indicating reasonable fit and < 2 suggesting very good fit. RMSEA indicates the fit of the model in the population's covariance matrix; with 0.05 considered "close" fit, < 0.08 reflecting moderate fit, and > 0.10 indicating unacceptable fit[10]. CFI compares the independence model (*i.e.,* worst possible fitting model) to the substantive model (*i.e.,* tested) with values ≥ 0.90 indicating good fit[10]. AIC will be used to compare the adequacy of the three models with the smallest AIC representing the best model[11].

Factor loadings were also used to determine the relative contribution of each manifest variable in explaining a latent construct. A higher factor loading indicated a stronger contribution of the variable to the latent construct. Standardized regression weights or path weights assessed the standard deviation change in an outcome variable (*e.g.,* the metabolic syndrome) for every one standard deviation unit change in a predictor variable (*e.g.,* PA). As the metabolic syndrome variable and the five risk factors were dichotomized (0 = does not meet criteria, and 1 = meets criteria), the standard deviation represents a percentage of the variable. Thus, the percent change in the outcome variable (for every standard deviation change in the predictor variable) was determined by multiplying the standardized path weight by the standard deviation of the outcome variable.

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PART IV

TOTAL ACTIVITY COUNTS AND BOUTED MINUTES OF MODERATE-TO-VIGOROUS PHYSICAL ACTIVITY: RELATIONSHIPS WITH CARDIOMETABOLIC BIOMARKERS USING 2003-2006 NHANES

This part is a paper by the same name that has been submitted to the Journal of Physical Activity and Health in 2014 by Dana L. Wolff, Eugene C. Fitzhugh, David R. Bassett, and James R. Churilla.

Wolff DL, Fitzhugh EC, Bassett DR, Churilla JR. Total activity counts and MVPA: Relationships with cardiometabolic biomarkers using 2003-2006 NHANES. *J Phys Act Health.* Under Review.

Abstract

PURPOSE: To contrast associations of accelerometer-measured moderate-to-vigorous physical activity (MVPA) accumulated in bouts and total activity counts (TAC) with cardiometabolic biomarkers in U.S. adults. METHODS: Using 2003 – 2006 National Health and Nutrition Examination Survey (NHANES) data, the sample was comprised of adults ≥ 20 years, not pregnant or lactating, with self-reported PA and at least 4 days of ≥ 10 hours accelerometer wear time (N = 5668). Bouted MVPA represented the minutes/day with ≥ 2020 counts/minute in bouts of 10 minutes or longer and TAC represented the total activity counts per day. Biomarkers included: cholesterol, triglyceride, glycohemoglobin, plasma glucose, C-peptide, insulin, C-reactive protein, homocysteine, blood pressure, body mass index (BMI), waist circumference, and skinfolds. Nested regression models were conducted which regressed each biomarker on bouted MVPA and TAC simultaneously, while adjusting for relevant covariates. RESULTS: Results indicated TAC was more strongly associated with 11 biomarkers: HDL-C, triglyceride, plasma glucose, C-peptide, insulin, C-reactive protein, homocysteine, systolic blood pressure, waist circumference, triceps skinfold, and subscapular skinfold. Bouted MVPA, however, only displayed stronger associations with BMI. CONCLUSIONS: The total volume of PA, represented by TAC, appears to have stronger associations with cardiometabolic biomarkers than MVPA accumulated in bouts.

Introduction

Physical activity (PA) has numerous health benefits including reduced risk of cardiovascular and metabolic diseases[1]. To further clarify the protective benefits of PA, epidemiologists and public health researchers continue to seek improved methods of assessing PA[2]. In order to address this issue, many population-based studies have begun to supplement self-report measures of PA with objective methods such as pedometers and accelerometers[3-5].

Accelerometers are widely accepted to provide valid and reliable measures of PA[6-8] and sedentary behavior[9,10]. However, there is concern that accelerometers may not provide quantitatively accurate measurements of time spent in various intensity categories (*i.e.,* sedentary, light, moderate, and vigorous). Specifically, studies in free-living environments have found that accelerometer-derived estimates of time spent in moderate-to-vigorous physical activity (MVPA) do not correspond with measurements obtained by portable indirect calorimetry[11-13]. For example, one study found the total amount of time spent in MVPA, regardless of bout duration, was underestimated by 50% when using National Health and Nutrition Examination Survey (NHANES) ActiGraph cut-points[11]. These results help to explain why 2003-2004 NHANES accelerometer data indicated that less than 5% of United States (U.S.) adults met recommended levels of PA (*i.e.,* $\geq$ 30 min of bouted MVPA, on 5 or more days/week), while approximately 51% met the recommendation based on NHANES self-report questionnaire data[14]. In general, most experts believe that the true prevalence lies somewhere in between these extremes. Another point is that various cut-point methods give estimates of time spent in bouted MVPA that fluctuate wildly; as much as a 10-fold difference in minutes of bouted MVPA[15]. Thus, the choice of cut-points has a significant impact on prevalence estimates of U.S. adults meeting PA guidelines.

An additional concern related to measuring PA with accelerometers is that most research focuses on MVPA performed in bouts. However, the exclusion of other intensity levels such as light PA and non-bout MVPA may underestimate the association between PA and cardiometabolic biomarkers. This is reflected in work by Healy et al.[16] which showed that individuals who perform greater amounts of light PA have a reduced incidence of diabetes. Kim al.[17] also found that individuals with higher levels of light-intensity PA were at lower risk for the metabolic syndrome, independent of MVPA. Furthermore, research related to sedentary behavior has indicated that light PA is highly inversely correlated with sedentary time (r = -0.98) after adjusting for wear time[18]. In addition to light PA, recent evidence suggests that MVPA accumulated in short, intermittent bouts may provide similar or additional benefits for cardiovascular and metabolic health, as MVPA accumulated in bouts of 10 minutes or longer[19-21]. The effects of both light PA and MVPA were highlighted by Loprinzi al.[22] who found individuals with the highest levels of both light PA and non-bout MVPA were least likely to be classified as having the metabolic syndrome. Given the importance of different sub-categories of PA intensity/duration, the most important variable to consider may be the total volume of PA performed.

Thus, we examined a global measure of PA captured by accelerometers, total activity counts (TAC) per day, which is a proxy for the total volume of PA performed. TAC mirrors the minutes spent in sedentary, light, moderate, and vigorous PA, and weights each minute according to intensity. While Troiano et al.[14] previously reported the mean values for total activity counts per minute for U.S. adults, no study has examined whether TAC shows stronger associations with cardiometabolic risk factors than MVPA in bouts of 10 minutes or longer. Therefore, the purpose of this study is to compare the associations of objectively measured

MVPA, accumulated in ≥ 10 minute bouts, and TAC with biomarkers in a representative sample of U.S. adults.

Methods

To answer the research question, the approach taken by Atienza et al.[5] was followed. Thus, we used the same data source and variable definitions, in addition to replicating the selection protocol. The NHANES is a cross-sectional survey utilizing a complex, multistage probability design in order to obtain a representative sample of the non-institutionalized U.S. population[23]. The NHANES data are collected during an in-person home interview and a visit to a mobile examination center (MEC). The interview collects demographic, socioeconomic, and health-related information. The examination consists of laboratory tests and medical and physiological measurements. Due to the availability of accelerometer data, the present study used data from the 2003–2004 and 2005–2006 NHANES cycles.

The sample was limited to adults ≥ 20 years of age with accelerometer data (N = 8228). Participants with less than four days of ≥ 10 hours of wear time (n = 2135), those missing self-reported PA data (n = 141), and pregnant or lactating women (n = 284) were excluded from the analysis, resulting in a final sample of 5668. The original survey protocols were approved by National Center for Health Statistics ethics review board, and informed consent was obtained from all NHANES participants. The University of Tennessee institutional review board approved the use of NHANES data in this analysis.

Accelerometer data collection and analysis

All ambulatory participants examined in the MEC were eligible to participate in the accelerometer component. Eligible participants were asked to wear an ActiGraph model 7164 activity monitor for seven days following their MEC examination. The ActiGraph model 7164

objectively measures vertical acceleration to indicate the intensity of bodily movement[24]. Participants were instructed to wear the monitor over their right hip during waking hours and to take it off for swimming or bathing[14]. Monitors were returned via mail to the NHANES contractor who downloaded that data and checked the calibration of the monitor. The acceleration signal was filtered, full-wave rectified, and integrated over a 1-min epoch[25].

Details of the accelerometer protocol can be found on the Centers for Disease Control and Prevention (CDC) website[26], and the Statistical Analysis Software (SAS) code for accelerometer data is available at the National Cancer Institute (NCI) website[27]. Data were recorded in 1-min epochs for the 7-day study period. Non-wear time was defined as ≥ 60 consecutive minutes with zero accelerometer counts, allowing up to two minutes with limited movement (< 100 counts/minute (cpm)). Daily wear time was determined by subtracting non-wear time from 24 hours. A valid day was defined as a day with 10 or more hours of monitor wear[28]. Only participants with at least four days of valid monitor wear were eligible to be included in this analysis.

The TAC variable was created by summing TAC per day and dividing it by the total number of valid wear days. The threshold for MVPA was defined ≥ 2020 cpm, as described by Troiano[14]. For the present analyses, only minutes of MVPA accumulated during bouts (≥ 10 consecutive min, allowing for 1-2 minutes below the 2020 cpm threshold) were used to create the bouted MVPA variable[28]. Minutes of bouted MVPA were then averaged across the total number of valid days. Since the denominator for the calculation of bouted MVPA is the total number of valid days, it is therefore possible to have an average below the 10-min bout threshold.

Outcomes

The outcome variables in this study were clinically measured and laboratory-based cardiometabolic biomarkers. Clinically measured biomarkers included: systolic blood pressure (SBP), diastolic blood pressure (DBP), body mass index (BMI), waist circumference, triceps skinfolds, and subscapular skinfolds. Laboratory-based biomarkers included: total cholesterol, high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), triglycerides, glycohemoglobin, plasma glucose, C-peptide, insulin, C-reactive protein, and homocysteine. More information on these biomarkers can be found online on the NHANES web site[24]. All biomarkers were treated continuously, with log transformation applied to biomarkers with non-normal distributions.

Covariates

Consistent with Atienza et al.[5], relevant socio-demographic, health/behavior status, and clinical diagnosis variables served as covariates in this analysis. Socio-demographic variables included: age (continuous variable), gender (male vs. female), race/ethnicity (recoded white vs. non-white), and education (recoded as less than high school, high school or general equivalency degree, and more than high school).

Smoking status, BMI, and general health condition were included to adjust for the health status of participants. Smoking status was categorized as current smoker and not current smoker. BMI was treated as a continuous variable in this analysis. General health condition was a self-report measure on a scale from one to five with a score of one indicating poor and five indicating excellent health.

Self-reported clinical diagnoses were included as covariates. Variables were dichotomized (yes/no) representing if participants had ever been diagnosed with the following

medical condition: diabetes, high blood pressure, osteoporosis, coronary heart disease, angina, and heart attack.

Statistical Analysis

All analyses were conducted using SAS 9.2 (SAS Institute, Inc., Cary, NC) and SAS-callable SUDAAN 11.0 (Research Triangle Park, NC) and accounted for the complex sampling design inherent to NHANES using sample weights calculated according to the NHANES analytical guidelines[21]. Weighted means and prevalence estimates were calculated for all variables utilized in this study.

Simple linear regressions were performed in which each biomarker was regressed on TAC and bouted MVPA, separately, after adjusting for age. In order to determine the independent association of both PA metrics with each biomarker, two nested regression models were conducted in which bouted MVPA and TAC were entered simultaneously. Model one adjusted for socio-demographic, health status, and clinical diagnosis variables. Model two adjusted for the same covariates in model one except BMI was added as a covariate. For both nested regression models, the variance inflation factors were < 5, indicating that the assumption of multicollinearity was not violated[29-31]. For both nested regression models, the adjusted Wald *F* statistic was used to determine which accelerometer measure had stronger associations with a biomarker. A larger adjusted Wald *F* statistic indicated a greater association with a biomarker[32]. For all analyses, statistical significance was assessed using two-tailed tests with $P \leq 0.05$.

Results

The weighted mean for TAC was 279,685 (*SE* = 2,708), with 6.9 (*SE* = 0.3) minutes spent in bouted MVPA. The average age of participants was 46.5 (*SE* = 0.1) years, with weighted means, geometric means, and medians for each biomarker are displayed in Table 1.

Prevalence estimates indicate the sample consisted of 50.6% females, 74.3% Non-Hispanic Whites, and 84.5% having attained a high school education/GED or greater. Only 35.6% of the respondents reported having a medical condition (*e.g.,* diabetes, high blood pressure, osteoporosis, etc.) and almost half (48.5%) reported their health condition as "excellent" or "very good."

Table 2 displays the results of age-adjusted, linear regressions. Of the 16 biomarkers, bouted MVPA and TAC were significantly associated with 13 biomarkers, while two biomarkers (*i.e.,* total cholesterol and DPB) had no significant association with either PA metric. Additionally, LDL-C was not significantly associated with bouted MVPA and homocysteine was not significantly associated with TAC. These results indicate that when examined separately, both TAC and bouted MVPA appear to be associated with cardiometabolic biomarkers.

Therefore, a more stringent set of regression analyses were performed to determine the independent associations of both PA metrics with biomarkers. Table 3 displays the results of these regression models, which simultaneously controlled for both PA indices. Results of model 1 indicated that after controlling for potential confounders, TAC displayed significant, independent associations with 12 biomarkers: HDL-C, triglycerides, plasma glucose, C-peptide, insulin, C-reactive protein, homocysteine, BMI, waist circumference, SBP, triceps skinfold, and subscapular skinfold (Table 3). Similarly, bouted MVPA displayed significant, independent associations with triglycerides and BMI. However, the adjusted Wald *F* statistics indicated only BMI was more strongly associated with bouted MVPA, while triglycerides was more strongly associated with TAC (Table 3).

After adjustment for BMI in model 2, bouted MVPA displayed significant, independent associations with two biomarkers: triglycerides and insulin (Table 4). However, TAC displayed

significant, independent associations with eight biomarkers: HDL, triglycerides, plasma glucose, C-peptide, insulin, C-reactive protein, homocysteine, and SBP. Except for triglycerides, the adjusted Wald *F* statistics for the aforementioned biomarkers were greater for TAC; indicating TAC had a stronger association with the biomarkers than MVPA. In addition, the standardized beta coefficient for triglycerides indicated an increase in triglycerides with increasing levels of bouted MVPA. Consistent with previous research, a decrease in triglyceride levels was found for increasing TAC. Thus, it was determined that TAC was more strongly associated with triglycerides.

Discussion

The current study provides insights into the objective measurement of PA using accelerometers, and has implications for epidemiological and public health research. The major finding was that TAC consistently displayed stronger associations with cardiometabolic biomarkers than bouted minutes of MVPA. Specifically, when examining both bouted MVPA and TAC simultaneously, several biomarkers were only associated with TAC (*i.e.,* HDL-C, glucose, triglycerides, C-peptide, C-reactive protein, homocysteine, SBP, waist circumference, triceps skinfolds, and subscapular skinfolds. In addition, only two biomarkers (*i.e.,* insulin and BMI) were found to have to have significant, independent associations with both MVPA and TAC. These results suggest that the total volume of PA, represented by TAC, may be more important to cardiometabolic health than MVPA accumulated in bouts of 10 minutes or longer. TAC is a marker of the total volume of PA, while bouted MVPA represents only a subset of the total volume.

Table 4.1: Weighted means, geometric means, and medians of cardiometabolic biomarkers among adults in the United States, NHANES 2003 – 2006.

Biomarker	*N*	Mean (SE)	Geometric Mean (SE)	Median (IQR)
Total Cholesterol (mg•dL^{-1})	5484	200.99 (0.64)	196.97 (0.62)	197.37 (172.20 – 224.30)
HDL-C (mg•dL^{-1})	5483	54.45 (0.29)	52.30 (0.27)	51.34 (41.89 – 62.97)
LDL-C (mg•dL^{-1})	2346	116.78 (0.89)	111.35 (0.86)	114.46 (90.97 – 137.52)
Triglyceride (mg•dL^{-1})	2417	145.56 (3.33)	120.87 (1.73)	114.92 (79.46 – 174.33)
Glycohemoglobin	5501	5.49 (0.02)	5.45 (0.02)	5.29 (5.06 – 5.56)
Glucose (plasma)	2428	102.45 (0.87)	100.28 (0.67)	96.94 (90.61 – 104.97)
C-peptide: SI (nmol•L^{-1})[a]	1248	0.83 (0.01)	0.75 (0.01)	0.75 (0.53 – 1.05)
Insulin (μU•mL^{-1})	2406	10.59 (0.21)	7.91 (0.16)	7.62 (4.79 – 13.02)
C-reactive protein (mg•dL^{-1})	5624	0.41 (0.01)	0.20 (0.001)	0.19 (0.08 – 0.44)
Homocysteine (μU•mL^{-1})[a]	2815	9.16 (0.13)	8.63 (0.10)	8.38 (7.02 – 10.30)
SBP	5433	123.68 (0.37)	122.41 (0.37)	120.54 (110.58 – 133.1)
DBP	5433	71.21 (0.15)	70.39 (0.26)	71.28 (63.71 – 78.32)
BMI	5622	28.30 (0.15)	27.68 (0.14)	27.27 (24.01 – 31.46)
Waist Circumference (cm)	5519	97.46 (0.35)	96.30 (0.33)	96.32 (86.47 – 106.99)
Triceps skinfold (mm)	5030	19.49 (0.18)	17.58 (0.17)	18.40 (12.91 – 25.64)
Subscapular skinfold (mm)	4408	20.17 (0.18)	18.67 (0.17)	14.13 (19.72 – 25.18)

N = sample size; SE = standard error; IQR = interquartile range; HDL-C = high density lipoprotein cholesterol; LDL-C = low density lipoprotein cholesterol; SBP = systolic blood pressure; DBP = diastolic blood pressure; BMI = body mass index.

[a] Only the NHANES 2003-2004 data were used due to unavailability of 2005-2006 data.

Table 4.2: Age-adjusted linear regressions – Relationship of accelerometer-determined moderate-to-vigorous physical activity (minutes per day) with biomarkers and mean daily total activity counts with biomarkers among U.S. adults, NHANES 2003 – 2006.

	MVPA			Mean daily total activity counts		
Biomarker	***β***	**(SE)**	**Adj. Wald *F***	***β***	**(SE)**	**Adj. Wald *F***
Total Cholesterol (mg•dL^{-1})	-0.02	(0.04)	0.33	0.000007	(0.000005)	1.98
HDL (mg•dL^{-1})	0.15	(0.03)	30.60****	0.000008	(0.000002)	14.62***
LDL (mg•dL^{-1})	-0.01	(0.08)	0.03	0.00002	(0.000008)	5.13*
Log Triglyceride (mg•dL^{-1})	-0.001	(0.0005)	8.26**	-0.0000003	(0.0000001)	16.77***
Log Glycohemoglobin (%)	-0.0003	(0.00005)	40.98****	-0.00000002	(0.00000000001)	9.62**
Log Glucose (plasma)	-0.00005	(0.0001)	23.61****	-0.00000006	(0.00000001)	14.16***
C-peptide: SI (nmol•L^{-1})[a]	-0.005	(0.001)	12.33**	-0.0000007	(0.0000001)	22.18****
Log Insulin (µU•mL^{-1})	-0.005	(0.0006)	52.47****	-0.000001	(0.0000001)	65.23****
Log C-reactive protein (mg•L^{-1})	-0.006	(0.0006)	85.06****	-0.0000008	(0.00000008)	102.11****
Log Homocysteine (µmol•mL^{-1})[a]	-0.0004	(0.0002)	6.51*	-0.00000003	(0.00000002)	1.21
SBP	-0.04	(0.01)	8.16**	-0.000003	(0.000002)	4.73*
DBP	-0.01	(0.01)	0.97	0.000002	(0.000002)	0.48
BMI	-0.08	(0.01)	93.31****	-0.000008	(0.0000007)	108.72****
Waist Circumference (cm)	-0.18	(0.02)	66.42****	-0.00002	(0.000002)	57.23****
Triceps skinfold (mm)	-0.09	(0.01)	116.55****	-0.00002	(0.000001)	288.44****
Subscapular skinfold (mm)	-0.07	(0.01)	52.71****	-0.000008	(0.000001)	45.38****

β = standardized beta.

[a] Only the NHANES 2003-2004 data were used in the analyses.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$.

Table 4.3: Simultaneous multiple regressions– relationship of mean daily moderate-to-vigorous physical activity and total accelerometer counts with cardiometabolic biomarkers among adults in the United States, NHANES 2003 – 2006.

	Model 1			Model 2		
Biomarker	***β***	**(SE)**	**Adj. Wald *F***	***β***	**(SE)**	**Adj. Wald *F***
Total Cholesterol ($mg \bullet dL^{-1}$)						
MVPA	-0.11	(0.09)	1.41	-0.1	(0.09)	1.11
TAC	0.00002	(0.00001)	1.97	0.00002	(0.00001)	2.20
HDL-C ($mg \bullet dL^{-1}$)						
MVPA	0.02	(0.03)	0.53	-0.007	(0.03)	0.07
TAC	0.00002	(0.000004)	14.04***	0.00001	(0.000004)	11.21**
LDL-C ($mg \bullet dL^{-1}$)						
MVPA	-0.06	(0.1)	0.24	-0.02	(0.13)	0.03
TAC	0.00001	(0.00001)	0.74	0.00001	(0.00001)	0.87
Log Triglyceride ($mg \bullet dL^{-1}$)						
MVPA	0.001	(0.0005)	4.88*	0.001	(0.0005)	8.12**
TAC	-0.0000003	(0.0000001)	5.48*	-0.0000003	(0.0000001)	4.55*
Log Glycohemoglobin (%)[a]						
MVPA	-0.0002	(0.0001)	3.68	-0.0002	(0.0001)	2.36
TAC	0.000000007	(0.00000002)	0.13	0.00000001	(0.00000002)	0.36
Log Glucose (plasma) [a]						
MVPA	-0.0002	(0.0002)	1.69	-0.00004	(0.0001)	0.13
TAC	-0.0000001	(0.00000002)	11.97**	-0.00000006	(0.00000002)	15.14***
C-peptide: SI ($nmol \bullet L^{-1}$)[b]						
MVPA	0.0002	(0.001)	0.03	0.002	(0.001)	3.98
TAC	-0.0000007	(0.0000001)	30.48****	-0.0000007	(0.0000001)	32.47****
Log Insulin ($\mu U \bullet mL^{-1}$)						
MVPA	0.0004	(0.0009)	0.27	0.002	(0.0008)	5.71*
TAC	-0.0000007	(0.0000001)	35.34****	-0.00000006	(0.0000001)	16.75***
Log C-reactive protein ($mg \bullet L^{-1}$)						
MVPA	-0.001	(0.001)	1.29	0.0001	(0.0009)	0.02
TAC	-0.0000005	(0.0000001)	28.24****	-0.0000004	(0.0000001)	16.86***
Log Homocysteine ($\mu mol \bullet mL^{-1}$) [b]						
MVPA	0.0002	(0.0003)	0.29	0.0002	(0.0003)	0.37
TAC	-0.0000001	(0.00000004)	7.48*	-0.0000001	(0.00000003)	7.73**
SBP [c]						
MVPA	0.005	(0.02)	0.04	0.02	(0.02)	0.52
TAC	-0.00001	(0.000004)	6.11*	-0.00001	(0.000004)	4.40*

Table 4.3: Continued.

	Model 1			Model 2		
Biomarker	***β***	**(SE)**	**Adj. Wald *F***	***β***	**(SE)**	**Adj. Wald *F***
DBP [c]						
MVPA	0.02	(0.03)	0.61	0.02	(0.02)	1.52
TAC	-0.000006	(0.000003)	2.73	-0.000004	(0.000004)	1.46
BMI						
MVPA	-0.04	(0.01)	7.58**	--		--
TAC	-0.000004	(0.000001)	6.95*	--		--
Waist Circumference (cm)						
MVPA	-0.06	(0.03)	2.84	--		--
TAC	-0.000015	(0.000003)	19.72***	--		--
Triceps skinfold (mm)						
MVPA	-0.01	(0.02)	0.37	--		--
TAC	-0.000008	(0.000002)	12.94**	--		--
Subscapular skinfold (mm)						
MVPA	-0.06	(0.02)	1.18	--		--
TAC	-0.000006	(0.000003)	4.49*	--		--

MVPA=moderate-to-vigorous physical activity; TAC=total accelerometer counts; *β*=standardized beta; SE=standard error; HDL-C=high density lipoprotein cholesterol; LDL-C=low density lipoprotein cholesterol; SBP=systolic blood pressure; DBP=diastolic blood pressure; BMI=body mass index.

Model 1: adjusted for age, gender, race, education, smoking, general perceived health, diabetes (yes/borderline vs. no), high blood pressure, osteoporosis, coronary heart disease, angina & heart attack; **Model 2:** adjusted for all covariates in model 2 & BMI.

[a] Model didn't include diabetes as a covariate.

[b] Only the NHANES 2003-2004 data were used due to unavailability of 2005-2006 data.

[c] Model didn't include high blood pressure as a covariate.

--, Not applicable as BMI is in the model; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$

The advantage to using TAC is that it incorporates all intensities and patterns of PA. Additionally, TAC is the most direct expression of what the accelerometer measures. If a uniform method of accelerometer data collection were established, TAC could be reported as a standardized measure. This could allow for comparisons to be drawn across studies using waist-worn ActiGraph accelerometers. TAC could also complement other measures of PA as it still allows reporting of other PA variables (*e.g.,* minutes spent in various intensity categories).

There are two key strengths of the current study. The first is the sampling design of NHANES, which produces a large, nationally representative sample of U.S. citizens. The second is that the use of accelerometers, an objective measure of PA, improves the precision with which PA is measured. It is also important to note there are several limitations of this study. Specifically, the use of a uniaxial, hip-worn accelerometer may have failed to capture non-ambulatory activity including cycling, weight training, and swimming. Also, the definition of MVPA in this study was limited to minutes accumulated in bouts of 10 minutes or longer and used a cut-point of ≥ 2020 cpm. This definition, however, is consistent with previous research using NHANES accelerometer data[5,14]. Another limitation is that accelerometer counts are dependent on the characteristics of the specific brand of PA monitor. Thus, the counts obtained from different device brands are not comparable to each other. However, the ActiGraph is the most common accelerometer used in PA research today. This was reflected in the results of a PubMed search (1990 to 2012), which revealed 56% of studies using accelerometers used the ActiGraph. Additionally, the ActiGraph has been shown to have adequate reliability and validity[9,33-35], providing stable results for acceleration in the vertical axis across multiple generations of the device[34,36-38].

In summary, the results of this study suggest that TAC is more strongly associated with cardiometabolic biomarkers than MVPA accumulated in ≥ 10 minute bouts. More importantly, TAC remained more strongly associated with biomarkers after adjustment for BMI. In contrast, bouted MVPA only displayed stronger associations with one biomarker (*i.e.,* BMI). Future studies are needed to examine the extent to which TAC is associated with chronic diseases.

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PART V

WAIST-WORN ACTIGRAPHY: POPULATION-REFERENCED PERCENTILES FOR TOTAL ACTIVITY COUNTS IN U.S. ADULTS

This part is a paper by the same name that has been accepted for publication in the Journal of Physical Activity and Health in 2014 by Dana L. Wolff, Eugene C. Fitzhugh, David R. Bassett, and James R. Churilla.

Wolff DL, Fitzhugh EC, Bassett DR, Churilla JR (In Press). Waist-worn Actigraphy: Population-referenced standards for total activity counts in U.S. adults. *J Phys Act Health.*

Abstract

BACKGROUND: Accelerometer-derived total activity counts is a measure of total physical activity (PA) volume. The purpose of this study was to develop age- and gender-specific percentiles for daily total activity counts (TAC), minutes of moderate-to-vigorous physical activity (MVPA), and minutes of light physical activity (LPA) in U.S. adults. METHODS: Waist-worn accelerometer data from the 2003 – 2006 NHANES were used for this analysis. The sample included adults ≥ 20 y with ≥ 10 h accelerometer wear time on ≥ 4 d (N = 6093). MVPA and LPA were defined as the number of one-min epochs with counts ≥ 2020 and 100 – 2019, respectively. TAC represented the activity counts acquired daily. TAC, MVPA, and LPA were averaged across valid days to produce a daily mean. RESULTS: Males in the 50th percentile accumulated 288,140 TAC/day, with 357 and 22 min/d spent in LPA and MVPA, respectively. The median for females was 235,741 TAC/d, with 349 and 12 min/d spent in LPA and MVPA, respectively. CONCLUSIONS: Population-referenced TAC percentiles reflect the total volume of PA, expressed relative to other adults. This is a different approach to accelerometer data reduction that complements the current method of looking at time spent in intensity sub-categories.

Introduction

Over the past two decades, the assessment of physical activity (PA) in research studies has shifted towards an increased use of objective monitors. In particular, waist-mounted accelerometers have gained acceptance with researchers as they provide reliable estimates of PA and can record both the amount and intensity of an individual's ambulatory movement[2-4]. Although these devices capture the intensity of activity, their ability to accurately identify the number of minutes spent in light, moderate, and vigorous intensity categories has been problematic[5-7].

One way to circumvent these inaccuracies is to use the accelerometer-derived total activity counts per day (TAC), which is a more direct expression of what the monitor records. More importantly, TAC is a measure of the total PA volume, and it incorporates all intensity categories, weighting each minute according to the intensity of the movement. Preliminary research by Wolff and colleagues[8] shows the importance of a global, objective measure of PA such as TAC. Using accelerometer data obtained from the 2003 – 2006 National Health and Nutrition Examination Survey (NHANES), they found that TAC had more robust associations with cardiometabolic biomarkers (*i.e.*, blood pressure, body mass index, cholesterol, etc.) than accelerometer-derived minutes spent in moderate-to-vigorous physical activity per day (MVPA)[8].

Intervention studies in adults and children have also begun to quantify PA using TAC[9-14]. For example, in a 12-month randomized-controlled trial, men in the treatment arm of a PA intervention had a 15% greater increase in TAC than participants in the control group[10]. Additionally, no association was found between the change in MVPA and the change in two-hour insulin levels, but a significant inverse association was demonstrated between the change in

TAC and the change in two-hour insulin levels. The results of this study provide further support for using TAC as a measure of PA.

TAC is a PA outcome measure that could provide a standardized measure of accelerometer-derived PA and allow for comparisons between studies. Thus, the main purpose of this study was to develop age- and gender-specific percentiles for TAC, MVPA, and minutes of light-intensity physical activity per day (LPA) in U.S. adults. A secondary purpose of this study was to compare the age-related decline in activity across percentiles of TAC, MVPA, and LPA.

Methods

The present study used data from the 2003 – 2006 National Health and Nutrition Examination Survey (NHANES). Data collected through NHANES are representative of the non-institutionalized U.S. population. Participants are selected using a complex, multistage probability design[15]. Each participant completes both an in-person home interview and a visit to a mobile examination center (MEC). Participant's demographic, socioeconomic, and health-related information are obtained during the interview, with the examination consisting of various medical and laboratory tests and measurements.

For this study, the sample was limited to adults 20 years and older with accelerometer data (N = 8228). Participants with less than four days that included ≥ 10 hours of wear time (n = 2135), were excluded from the analysis, resulting in the final sample (N = 6093). The original survey protocols were approved by National Center for Health Statistics ethics review board, and informed consent was obtained from all NHANES participants. The University of Tennessee institutional review board approved the use of NHANES data in this analysis.

Accelerometer data collection and analysis

All ambulatory individuals examined in the MEC were eligible participants for the accelerometer component. Eligible participants were instructed to wear an ActiGraph model 7164 accelerometer on their right hip during waking hours for seven days, and to remove it when swimming or bathing[16]. Details of the accelerometer protocol can be found on the Centers for Disease Control and Prevention (CDC) website[17]. The ActiGraph model 7164 is a uniaxial accelerometer measuring vertical acceleration in one-minute epochs. Vertical accelerations are filtered, full-wave rectified, and integrated over time[18], resulting in "activity counts per minute" that correspond to the intensity of ambulatory activity[19].

Accelerometer data were analyzed using the SAS macro provided by the National Cancer Institute website[20]. Non-wear time was defined as ≥ 60 consecutive minutes with zero accelerometer counts, allowing up to two minutes with limited movement (< 100 counts/min). Daily wear time was determined by subtracting non-wear time from 24 hours. A valid day was defined as a day with 10 or more hours of monitor wear[21]. Only participants with at least four valid days of monitor wear time were eligible to be included in this analysis. The TAC variable was created by averaging the total counts per day across all valid days. Using thresholds described by Troiano[16], LPA was defined as the total number of minutes with 100 – 2019 counts/min, while MVPA was defined the total number of minutes with ≥ 2020 counts/min. LPA and MVPA were averaged across all valid days.

Statistical Analysis

Descriptive analyses were conducted using SAS 9.2 (SAS Institute, Inc., Cary, NC) and SAS-callable SUDAAN 11.0 (Research Triangle Park, NC) and accounted for the complex sampling design using sample weights calculated according to NHANES analytical guidelines[15].

Age-adjusted prevalence estimates and weighted means were calculated for all variables utilized in this study.

Smoothed, sex- and age-specific percentile curves corresponding to the 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th were calculated using the LMS method. The LMS method is a statistical approach that normalizes a measure (*i.e.,* TAC, MVPA, or LPA) across age using a Box–Cox power transformation[22]. The LMS parameters are skewness (L: Box–Cox power), median (M), and coefficient of variation (S). At each age, penalized likelihood is used to fit the L, M, and S parameters as cubic splines[22]. Models that minimize the deviance and provide good fit for the LMS parameters are selected to achieve smooth curves. In the present analysis, LMS curves were generated using LMS ChartmakerPro (LMS Chartmaker version 2.54) software, which adjusts for NHANES sample weights.

Results

Demographic characteristics of the 6093 adults included in this analysis are presented in Table 1. The average age of participants was 48.3 (*SE* = 0.4) years and age-adjusted prevalence estimates indicated the sample consisted of 51.5% females, 73.1% Non-Hispanic Whites, and 84.3% having attained a high school education/GED or greater. As shown by the 50th percentile or median, males accumulated 282,476 TAC per day, with approximately 352 minutes per day spent in LPA and 22 minutes per day spent in MVPA. Females in the 50th percentile accumulated 234,322 TAC per day, with approximately 351 minutes per day spent in LPA and 12 minutes per day spent in MVPA. For tables including percentile values please see the supplemental content (Tables 4.2 – 4.7).

Figure 1 presents age- and gender-specific TAC percentiles. Across all ages, TAC was consistently higher in males than females. For males at or above the 50th percentile, the highest

levels of TAC were seen at age 20, with TAC then declining with increasing age. In females above the 50th percentile, TAC peaked between 38 to 41 years of age before a steady decline was seen with increasing age.

Table 5.1: Characteristics of Study Population

Variable	% (SE)
Age in years ($\bar{X}$ ± SE)	48.3 ± 0.4
Gender	
Female	51.5 (0.7)
Male	48.5 (0.7)
Race/ethnicity	
Non-Hispanic White	73.1 (2.1)
Non-Hispanic Black	9.8 (1.2)
Mexican American	8.2 (1.1)
Other	8.9 (0.5)
Education Level	
< HS	15.7 (0.6)
HS Degree/GED	25.4 (0.8)
Some College or AA	32.1 (0.9)
≥ College Degree	26.8 (1.5)

Note: Prevalence estimates are age-adjusted.
SE: Standard Error; HS: High School; GED: General Equivalency Degree; AA: Associate of Arts.

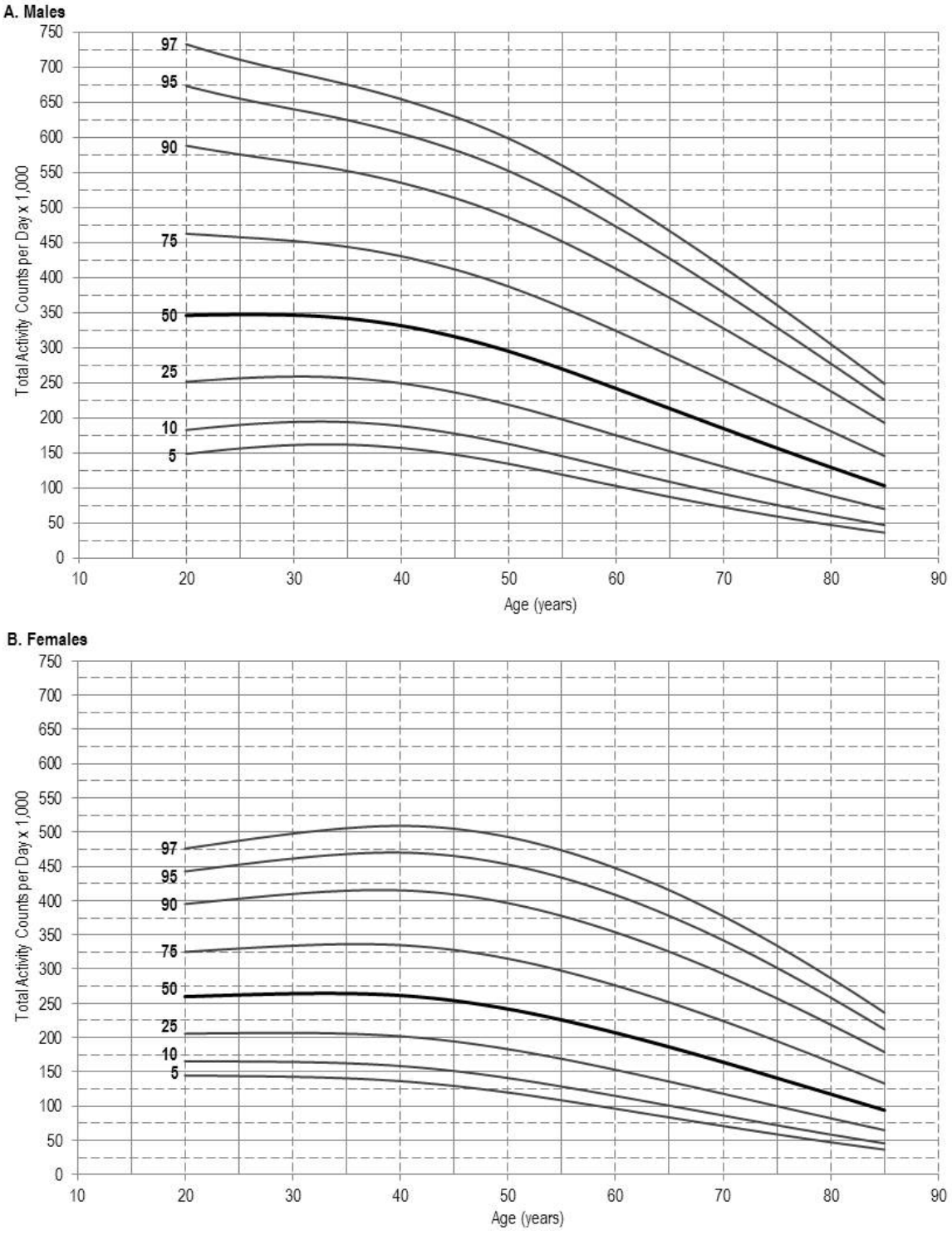

Figure 5.1: Percentiles of daily total activity counts for males (A) and females (B), 20+ years of age: 2003 – 2006 National Health and Nutrition Examination Survey.
Note: Data obtained with waist-worn accelerometer (ActiGraph 7164).

Age- and gender-specific percentiles for MVPA are displayed in Figure 2. MVPA was consistently higher in males than females and was highest at 20 years of age. An exception was seen for females in the 95th and 97th percentiles, where the highest levels of MVPA were seen at age 42 and 54, respectively. Age-related declines were also seen in both genders. Specifically, 90% of males between 20 to 42 years of age accumulated 10 minutes or more of MVPA per day compared to less than 10% of males 85 years of age and older. Similarly, 75% of females between 20 to 36 years of age accumulated 10 minutes or more of MVPA per day compared to less than 5% of those 85+ years of age.

LPA percentiles specific to age and gender are presented in Figure 3. For males, LPA peaked between 35 to 40 years of age. In females, LPA peaked between the ages of 45 and 51 years of age, before beginning to decline. Additionally, in the 5th and 10th percentiles females acquired greater amounts of LPA compared to males. Between the 25th and 50th percentiles males in their mid to late forty's or younger accumulated higher levels of LPA than females.

Figure 4 compares the percent change in TAC, LPA, and MVPA with increasing age for the 50th percentile of U.S. adults. In males, TAC began a steady decline at age 35, with a 73% decrease seen by age 85. In females, a decline in TAC began at age 40, resulting in a 66% decrease by age 85. Minutes spent in LPA increased in females through age 50 and males through age 40. The decline in LPA after the aforementioned ages resulted in a decrease of 37% in males and 33% in females by the time individuals reached 85 years of age. The magnitude of the change in MVPA with increasing age was the highest of the three PA measures, with a 95% and 92% decrease in MVPA seen between 20 and 85 years of age, in males and females, respectively.

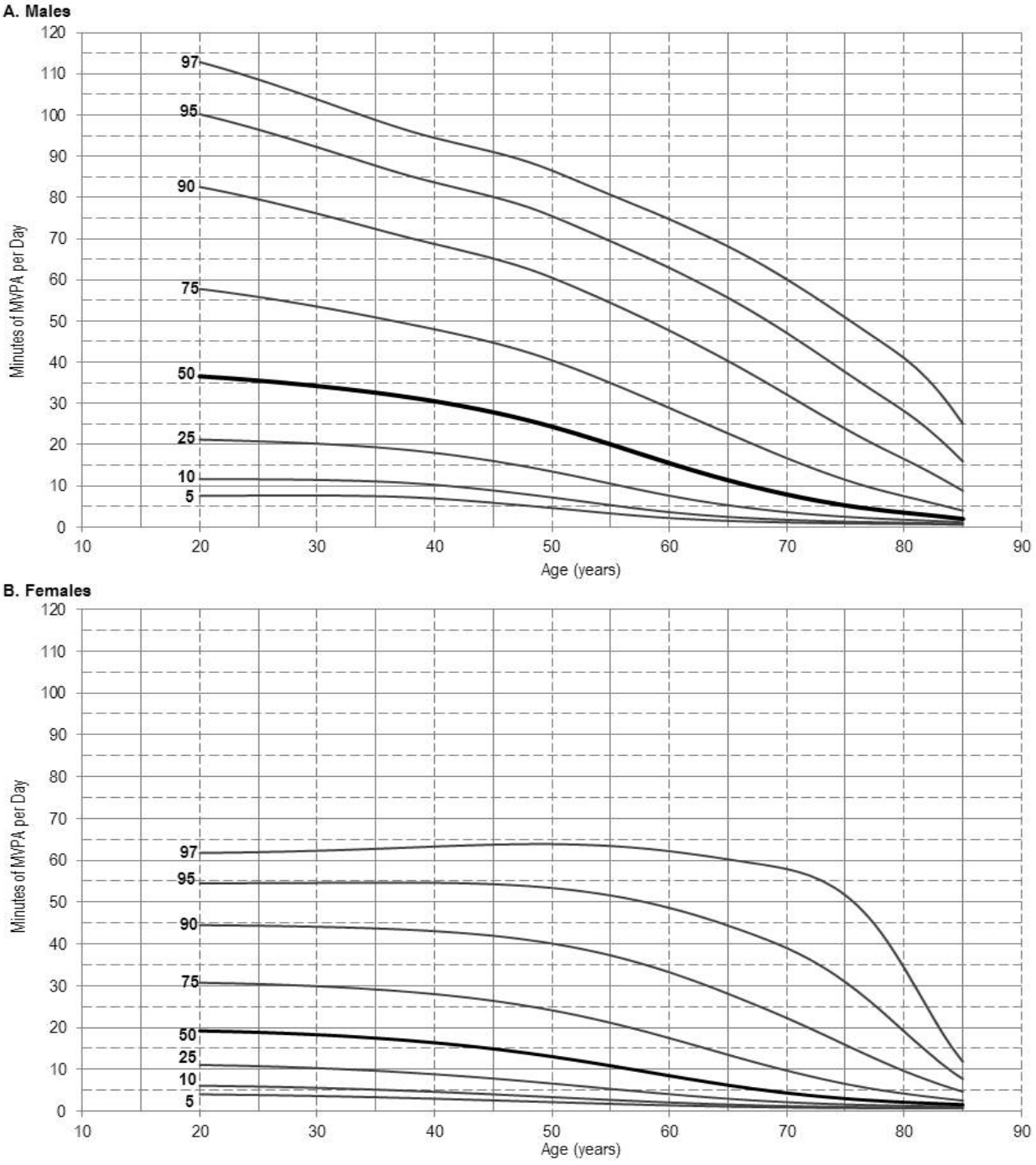

Figure 5.2: Percentiles of daily minutes of moderate to vigorous physical activity for males (A) and females (B), 20+ years of age: 2003 – 2006 National Health and Nutrition Examination Survey.
Note: Data obtained with waist-worn accelerometer (ActiGraph 7164).

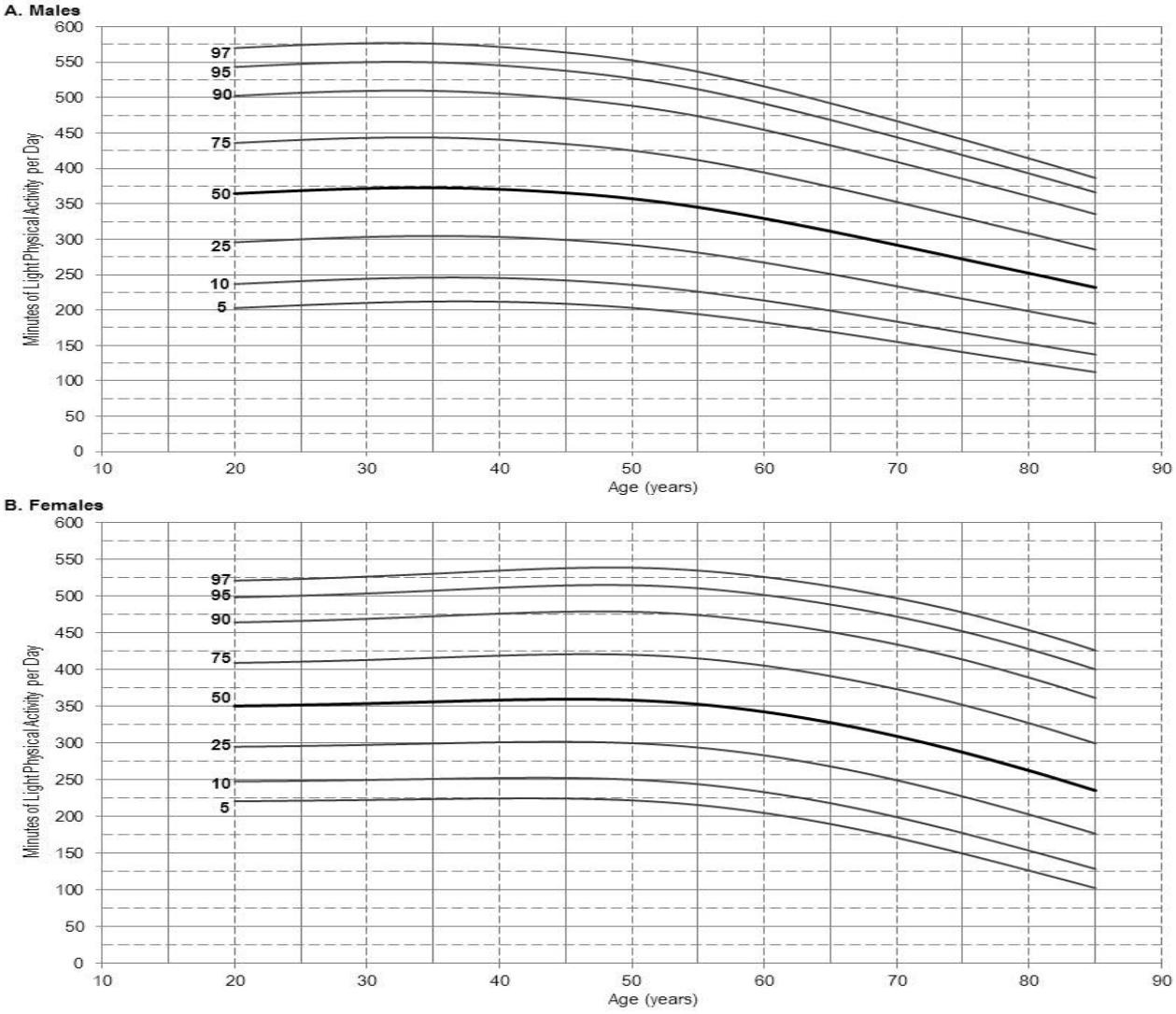

Figure 5.3: Percentiles of daily minutes of light physical activity for males (A) and females (B), 20+ years of age: 2003 – 2006 National Health and Nutrition Examination Survey.
Note: Data obtained with waist-worn accelerometer (ActiGraph 7164).

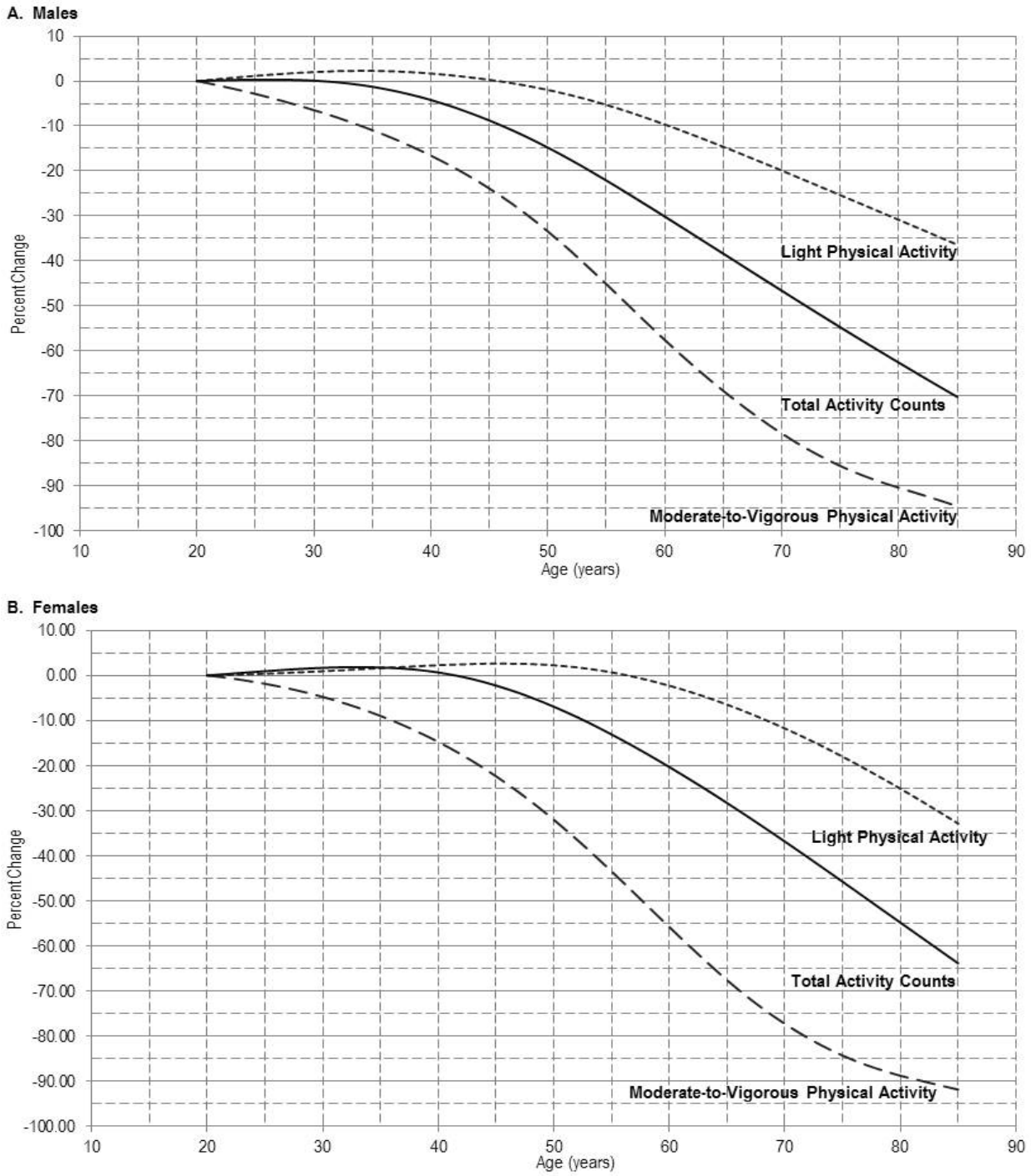

Figure 5.4: Relationship of accelerometer-derived physical activity levels and age, for males (A) and females (B) 20+ years of age in the 50th percentile: 2003 – 2006 National Health and Nutrition Examination Survey.

Discussion

This study is the first to report population-referenced data for TAC in U.S. adults. These percentiles provide researchers with a measure of the total volume of PA that can be expressed relative to others of the same age and gender (*i.e.,* as percentiles). Furthermore, these results provide insights into how the intensity and volume of PA changes throughout adulthood.

Consistent with previous research, our results indicate TAC, LPA, and MVPA levels were higher in males than females[16,23]. A dramatic decline in MVPA was seen in individuals older than 20 - 29 years of age. However, LPA remained relatively stable until age 50 - 59 years, and only declined in older age groups. The age-related decline in LPA was much less pronounced than the decline in MVPA. As a result, the age-related decline in TAC was modest, since this metric incorporates both LPA and MVPA.

Our results indicate that while there is a modest age-related decline in the total volume of PA (*i.e.,* TAC), LPA remains fairly stable over much of the adult lifespan. However, the standard cut-point for MVPA (*i.e.,* 2020 counts/min) gives the impression that older adults perform little to no MVPA in one-minute bouts. This finding is consistent with previous research indicating that the use of cut-point methods can result in misclassification of time spent in different intensities, particularly in older adults[24]. In fact, the 2008 national PA recommendations state that relative intensity, rather than absolute intensity, should be used for older adults and individuals with impaired functional capacities[25-27]. Thus, a limitation of the current study, and most other accelerometer studies, is that an absolute cut-point was used to define the lower bounds of MVPA.

TAC is a useful metric because it captures all PA performed, regardless of the intensity, frequency, or duration of the activities. This is important because previous research has

demonstrated that both LPA[28] and MVPA accumulated in bouts less than 10 minutes[29] are associated with health benefits. TAC is simple to calculate and can easily be converted to age and gender specific percentiles. Additionally, this measure allows for standardization of PA for studies using waist-worn ActiGraph accelerometers and it still allows researchers to report other measures of PA (*e.g.,* minutes spent in various intensity categories). Hence, TAC complements, rather than replaces, other PA variables.

A potential criticism of TAC is that it has no intuitive meaning. However, when Quetelet first proposed the index that later became known as body mass index (BMI)[30,31], that metric had no intuitive meaning either. BMI gained acceptance with the development of population reference data, and eventually criterion-referenced standards were developed that gave meaning to the units. Thus, we believe the same thing could apply to TAC if it were to be used as a standardized measure of accelerometer-derived PA.

This paper describes population-referenced TAC percentiles, for the U.S. adult population. These percentiles can provide PA and public health researchers with a measure of the total volume of PA, allowing comparisons to be made at the individual and population levels. Future research should explore the use of TAC in establishing criterion-based standards for PA. Towards this end, we are currently conducting follow-up studies exploring the relationships of TAC with various health indicators.

Acknowledgments

The authors would like to thank Dr. Tim Cole for providing advice pertaining to the smoothing procedure within LMSChartmaker Pro.

Table 5.2: Percentiles for Waist-Worn Accelerometer-Derived Total Activity Counts in US Males (*N*=3002).

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.32	345920	0.45	148253	182516	251151	345920	462459	587941	673129	732725
21	0.32	346218	0.45	149988	184115	252309	346218	461435	585269	669238	727943
22	0.32	346497	0.44	151666	185656	253420	346497	460444	582698	665502	723354
23	0.32	346741	0.44	153263	187118	254462	346741	459474	580224	661920	718964
24	0.32	346918	0.43	154754	188473	255408	346918	458491	577811	658457	714734
25	0.32	347018	0.43	156128	189711	256247	347018	457487	575455	655108	710663
26	0.32	347046	0.42	157380	190827	256977	347046	456472	573166	651889	706767
27	0.32	347000	0.42	158505	191819	257598	347000	455447	570951	648807	703055
28	0.32	346862	0.42	159488	192670	258092	346862	454389	568782	645832	699495
29	0.32	346609	0.42	160315	193365	258439	346609	453270	566627	642926	696046
30	0.32	346217	0.41	160977	193892	258625	346217	452060	564442	640040	692654
31	0.32	345666	0.41	161462	194239	258632	345666	450728	562193	637133	689273
32	0.32	344935	0.41	161761	194394	258447	344935	449247	559838	634157	685852
33	0.32	344006	0.41	161866	194348	258056	344006	447594	557353	631084	682358
34	0.32	342865	0.41	161769	194090	257447	342865	445750	554713	627886	678762
35	0.32	341505	0.40	161465	193618	256615	341505	443706	551904	624546	675046
36	0.32	339923	0.40	160955	192931	255560	339923	441458	548922	621058	671203
37	0.32	338115	0.40	160236	192026	254278	338115	438998	545756	617411	667217
38	0.32	336083	0.40	159311	190905	252771	336083	436329	542408	613606	663094
39	0.32	333826	0.40	158179	189569	251039	333826	433448	538875	609638	658825
40	0.32	331335	0.40	156842	188016	249078	331335	430342	535137	605483	654384
41	0.32	328611	0.41	155305	186252	246891	328611	427006	531181	601126	649752
42	0.32	325664	0.41	153580	184288	244490	325664	423447	527015	596569	644931
43	0.32	322507	0.41	151679	182139	241888	322507	419679	522648	591822	639929
44	0.32	319149	0.41	149615	179815	239097	319149	415707	518084	586886	634744
45	0.32	315593	0.41	147397	177324	236121	315593	411530	513315	581748	629361
46	0.32	311837	0.41	145031	174674	232966	311837	407136	508320	576381	623750
47	0.32	307875	0.41	142527	171869	229630	307875	402511	503071	570750	617866
48	0.32	303698	0.42	139891	168915	226116	303698	397635	497540	564817	611668
49	0.32	299309	0.42	137131	165820	222428	299309	392505	491716	558566	605137
50	0.32	294720	0.42	134261	162597	218581	294720	387133	485606	552003	598274
51	0.32	289949	0.43	131296	159262	214590	289949	381534	479226	545142	591096
52	0.32	285015	0.43	128253	155833	210474	285015	375729	472597	538003	583620
53	0.32	279937	0.43	125146	152325	206252	279937	369735	465734	530601	575861

Table 5.2: Continued

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
54	0.32	274730	0.43	121990	148754	201937	274730	363569	458653	522950	567833
55	0.32	269409	0.44	118797	145132	197546	269409	357245	451367	515063	559546
56	0.32	263989	0.44	115579	141472	193091	263989	350779	443892	506957	551018
57	0.32	258487	0.44	112347	137787	188588	258487	344188	436248	498649	542267
58	0.32	252920	0.45	109112	134090	184050	252920	337493	428455	490163	533315
59	0.32	247303	0.45	105885	130391	179491	247303	330710	420531	481516	524183
60	0.32	241648	0.46	102675	126701	174923	241648	323851	412490	472723	514884
61	0.32	235964	0.46	99487	123026	170353	235964	316928	404343	463794	505428
62	0.32	230262	0.46	96329	119373	165789	230262	309951	396102	454744	495829
63	0.32	224548	0.47	93203	115748	161239	224548	302930	387778	445581	486099
64	0.32	218831	0.47	90116	112156	156708	218831	295871	379376	436313	476242
65	0.32	213111	0.47	87068	108598	152197	213111	288778	370900	426941	466261
66	0.32	207393	0.48	84062	105077	147712	207393	281652	362351	417468	456158
67	0.32	201679	0.48	81100	101596	143253	201679	274497	353733	407895	445933
68	0.32	195973	0.48	78183	98156	138823	195973	267317	345050	398229	435593
69	0.32	190278	0.49	75313	94759	134426	190278	260117	336306	388473	425143
70	0.32	184598	0.49	72490	91407	130063	184598	252900	327508	378633	414589
71	0.32	178935	0.49	69717	88101	125738	178935	245671	318660	368717	403937
72	0.32	173295	0.50	66994	84843	121452	173295	238437	309771	358733	393198
73	0.32	167680	0.50	64321	81634	117208	167680	231201	300846	348687	382378
74	0.32	162093	0.51	61698	78475	113006	162093	223967	291891	338586	371484
75	0.32	156537	0.51	59127	75366	108850	156537	216741	282912	328437	360526
76	0.32	151014	0.51	56607	72308	104739	151014	209526	273915	318249	349511
77	0.32	145527	0.52	54137	69300	100676	145527	202327	264905	308026	338445
78	0.32	140076	0.52	51717	66343	96659	140076	195143	255885	297771	327332
79	0.32	134661	0.52	49346	63435	92689	134661	187976	246854	287486	316174
80	0.32	129282	0.53	47023	60576	88765	129282	180827	237816	277173	304972
81	0.32	123940	0.53	44748	57765	84887	123940	173696	228771	266833	293730
82	0.32	118634	0.53	42518	55001	81054	118634	166585	219721	256471	282449
83	0.32	113367	0.53	40335	52285	77267	113367	159496	210671	246090	271138
84	0.32	108140	0.54	38197	49615	73527	108140	152433	201626	235698	259802
85+	0.32	102955	0.54	36105	46993	69834	102955	145400	192592	225301	248450

Table 5.3 Percentiles for Waist-Worn Accelerometer-Derived Total Activity Counts in U.S. Females (*N*=3091).

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.17	259903	0.34	144810	165610	205895	259903	325218	395166	442712	476069
21	0.17	260403	0.34	144633	165532	206041	260403	326210	396746	444720	478389
22	0.17	260898	0.34	144459	165454	206185	260898	327194	398313	446713	480693
23	0.17	261394	0.34	144289	165381	206331	261394	328175	399876	448701	482991
24	0.17	261887	0.35	144123	165310	206478	261887	329151	401429	450677	485275
25	0.17	262366	0.35	143954	165235	206617	262366	330107	402957	452622	487526
26	0.17	262821	0.35	143775	165147	206737	262821	331030	404443	454520	489726
27	0.17	263245	0.35	143581	165040	206834	263245	331916	405884	456369	491874
28	0.17	263635	0.35	143366	164910	206902	263635	332760	407278	458167	493967
29	0.17	263982	0.35	143125	164752	206936	263982	333553	408613	459902	495996
30	0.17	264274	0.36	142851	164555	206924	264274	334282	409874	461556	497940
31	0.17	264497	0.36	142533	164309	206853	264497	334929	411043	463112	499781
32	0.17	264641	0.36	142163	164006	206716	264641	335485	412109	464558	501508
33	0.17	264696	0.36	141736	163639	206502	264696	335938	413060	465883	503108
34	0.17	264649	0.36	141242	163198	206202	264649	336274	413879	467066	504563
35	0.17	264492	0.36	140677	162679	205810	264492	336482	414554	468095	505856
36	0.17	264217	0.37	140036	162074	205317	264217	336552	415073	468958	506977
37	0.17	263810	0.37	139309	161374	204712	263810	336469	415419	469636	507904
38	0.17	263254	0.37	138487	160569	203982	263254	336211	415567	470102	508611
39	0.17	262529	0.37	137561	159647	203111	262529	335755	415486	470320	509057
40	0.17	261620	0.37	136522	158598	202089	261620	335077	415149	470259	509210
41	0.17	260514	0.38	135367	157416	200905	260514	334163	414535	469897	509044
42	0.17	259207	0.38	134092	156101	199558	259207	333007	413637	469223	508548
43	0.17	257699	0.38	132699	154650	198047	257699	331606	412453	468237	507721
44	0.17	255993	0.38	131191	153069	196375	255993	329965	410987	466940	506567
45	0.17	254094	0.39	129573	151362	194548	254094	328090	409244	465342	505092
46	0.17	252010	0.39	127849	149534	192571	252010	325987	407233	463447	503303
47	0.17	249744	0.39	126025	147590	190450	249744	323661	404956	461260	501202
48	0.17	247302	0.40	124105	145536	188190	247302	321116	402415	458780	498789
49	0.17	244689	0.40	122097	143378	185797	244689	318355	399613	456009	496065
50	0.17	241915	0.40	120009	141126	183281	241915	315389	396560	452956	493039
51	0.17	238990	0.41	117849	138786	180650	238990	312228	393267	449633	489721
52	0.17	235923	0.41	115622	136367	177913	235923	308882	389743	446049	486121
53	0.17	232721	0.41	113337	133876	175078	232721	305357	385993	442208	482242

Table 5.3: Continued.

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
54	0.17	229389	0.42	111000	131319	172149	229389	301657	382018	438107	478079
55	0.17	225935	0.42	108617	128704	169136	225935	297787	377823	433751	473637
56	0.17	222368	0.42	106196	126038	166047	222368	293759	373418	429150	468924
57	0.17	218697	0.43	103743	123328	162888	218697	289580	368812	424313	463950
58	0.17	214930	0.43	101265	120582	159669	214930	285261	364014	419247	458722
59	0.17	211076	0.43	98769	117806	156398	211076	280809	359032	413961	453248
60	0.17	207142	0.44	96260	115007	153081	207142	276233	353873	408461	447532
61	0.17	203133	0.44	93741	112189	149722	203133	271535	348539	402748	441577
62	0.17	199052	0.44	91216	109353	146324	199052	266719	343035	396827	435385
63	0.17	194902	0.45	88687	106505	142892	194902	261791	337365	390701	428961
64	0.17	190688	0.45	86157	103645	139428	190688	256752	331530	384371	422303
65	0.17	186413	0.46	83627	100778	135936	186413	251606	325533	377838	415415
66	0.17	182080	0.46	81102	97906	132418	182080	246357	319377	371107	408297
67	0.17	177694	0.46	78584	95033	128879	177694	241008	313066	364179	400954
68	0.17	173257	0.47	76074	92160	125322	173257	235563	306603	357058	393385
69	0.17	168772	0.47	73575	89290	121748	168772	230024	299990	349745	385595
70	0.17	164243	0.47	71089	86425	118161	164243	224396	293231	342243	377584
71	0.17	159674	0.48	68617	83568	114564	159674	218681	286330	334556	369357
72	0.17	155068	0.48	66163	80721	110961	155068	212887	279293	326692	360921
73	0.17	150431	0.49	63728	77887	107354	150431	207019	272127	318658	352285
74	0.17	145768	0.49	61314	75068	103748	145768	201082	264840	310462	343455
75	0.17	141083	0.49	58924	72268	100147	141083	195085	257440	302113	334443
76	0.17	136384	0.50	56559	69490	96554	136384	189035	249938	293625	325264
77	0.17	131676	0.50	54223	66736	92975	131676	182941	242346	285010	315930
78	0.17	126966	0.50	51916	64009	89413	126966	176813	234675	276281	306456
79	0.17	122256	0.51	49641	61310	85871	122256	170653	226930	267445	296849
80	0.17	117549	0.51	47397	58640	82348	117549	164465	219115	258506	287114
81	0.17	112844	0.52	45183	55998	78846	112844	158249	211232	249466	277254
82	0.17	108141	0.52	42999	53383	75364	108141	152006	203280	240325	267266
83	0.17	103441	0.52	40844	50797	71901	103441	145736	195259	231082	257152
84	0.17	98746	0.53	38720	48238	68460	98746	139442	187175	221743	246918
85+	0.17	94061	0.53	36628	45710	65043	94061	133131	179035	212318	236573

Table 5.4: Percentiles for Waist-Worn Accelerometer-Derived Minutes of Moderate-to-Vigorous Physical Activity in U.S. Males (*N*=3002)

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.35	37	0.74	8	12	21	37	58	83	100	113
21	0.35	36	0.73	8	12	21	36	57	82	99	112
22	0.35	36	0.73	8	12	21	36	57	81	99	111
23	0.35	36	0.73	8	12	21	36	57	81	98	110
24	0.35	36	0.73	8	12	21	36	56	80	97	110
25	0.35	36	0.72	8	12	21	36	56	80	96	109
26	0.34	35	0.72	8	12	21	35	55	79	96	108
27	0.34	35	0.72	8	12	21	35	55	78	95	107
28	0.34	35	0.72	8	12	20	35	54	78	94	106
29	0.34	35	0.72	8	11	20	35	54	77	93	105
30	0.34	34	0.71	8	11	20	34	54	76	92	104
31	0.33	34	0.71	8	11	20	34	53	75	91	103
32	0.33	34	0.71	8	11	20	34	52	75	90	102
33	0.33	33	0.71	8	11	20	33	52	74	89	101
34	0.33	33	0.71	8	11	20	33	51	73	89	100
35	0.33	33	0.71	7	11	19	33	51	72	88	99
36	0.32	32	0.71	7	11	19	32	50	72	87	98
37	0.32	32	0.71	7	11	19	32	50	71	86	97
38	0.32	31	0.71	7	11	19	31	49	70	85	96
39	0.32	31	0.72	7	10	18	31	49	69	84	95
40	0.31	31	0.72	7	10	18	31	48	69	84	94
41	0.31	30	0.73	7	10	18	30	47	68	83	94
42	0.31	30	0.73	7	10	17	30	47	67	82	93
43	0.30	29	0.74	6	9	17	29	46	67	82	92
44	0.30	28	0.75	6	9	16	28	45	66	81	92
45	0.30	28	0.76	6	9	16	28	45	65	80	91
46	0.29	27	0.76	6	9	16	27	44	64	79	90
47	0.29	27	0.77	5	8	15	27	43	64	79	89
48	0.29	26	0.79	5	8	15	26	42	63	78	89
49	0.28	25	0.80	5	8	14	25	41	62	77	88
50	0.28	24	0.81	5	7	13	24	40	61	75	87
51	0.27	24	0.82	4	7	13	24	39	59	74	85
52	0.27	23	0.83	4	6	12	23	38	58	73	84

Table 5.4 Continued.

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
53	0.26	22	0.85	4	6	12	22	37	57	72	83
54	0.25	21	0.86	4	6	11	21	36	56	71	82
55	0.25	20	0.88	3	5	11	20	35	54	69	81
56	0.24	19	0.90	3	5	10	19	34	53	68	79
57	0.23	18	0.92	3	5	9	18	33	52	67	78
58	0.22	17	0.94	3	4	9	17	31	50	66	77
59	0.21	16	0.96	2	4	8	16	30	49	64	76
60	0.20	16	0.98	2	4	8	16	29	48	63	75
61	0.19	15	1.00	2	3	7	15	28	46	62	73
62	0.18	14	1.02	2	3	7	14	26	45	60	72
63	0.16	13	1.04	2	3	6	13	25	43	59	71
64	0.15	12	1.06	2	3	6	12	24	42	57	70
65	0.13	11	1.08	2	2	5	11	23	40	56	68
66	0.12	11	1.09	1	2	5	11	22	39	54	67
67	0.10	10	1.10	1	2	5	10	20	37	52	65
68	0.08	9	1.11	1	2	4	9	19	35	51	64
69	0.07	9	1.12	1	2	4	9	18	34	49	62
70	0.05	8	1.13	1	2	4	8	17	32	47	60
71	0.03	7	1.14	1	2	3	7	16	30	45	58
72	0.01	7	1.14	1	2	3	7	15	29	43	57
73	-0.02	6	1.14	1	1	3	6	13	27	41	55
74	-0.04	6	1.13	1	1	3	6	12	25	40	53
75	-0.06	5	1.13	1	1	3	5	11	24	38	51
76	-0.08	5	1.12	1	1	2	5	11	22	36	49
77	-0.11	4	1.11	1	1	2	4	10	21	34	47
78	-0.13	4	1.09	1	1	2	4	9	19	32	45
79	-0.16	4	1.07	1	1	2	4	8	18	30	43
80	-0.18	4	1.05	1	1	2	4	8	17	28	41
81	-0.21	3	1.03	1	1	2	3	7	15	26	39
82	-0.23	3	1.01	1	1	2	3	6	14	24	36
83	-0.26	3	0.98	1	1	1	3	5	12	21	33
84	-0.29	2	0.95	1	1	1	2	5	10	19	29
85+	-0.32	2	0.93	1	1	1	2	4	9	16	25

Table 5.5: Percentiles for Waist-Worn Accelerometer-Derived Minutes of Moderate-to-Vigorous Physical Activity in U.S. Females (*N*=3091)

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.32	19.20	0.75	4	6	11	19	31	44	54	62
21	0.31	19.15	0.75	4	6	11	19	31	44	54	62
22	0.31	19.08	0.75	4	6	11	19	31	44	54	62
23	0.31	19.01	0.76	4	6	11	19	31	44	55	62
24	0.31	18.94	0.76	4	6	11	19	30	44	55	62
25	0.31	18.85	0.76	4	6	11	19	30	44	55	62
26	0.30	18.76	0.77	4	6	11	19	30	44	55	62
27	0.30	18.65	0.77	4	6	11	19	30	44	55	62
28	0.30	18.54	0.77	4	6	11	19	30	44	55	62
29	0.29	18.42	0.78	4	6	10	18	30	44	55	62
30	0.29	18.29	0.78	4	6	10	18	30	44	55	62
31	0.29	18.15	0.79	4	6	10	18	30	44	55	62
32	0.28	18.00	0.79	4	5	10	18	30	44	55	62
33	0.28	17.84	0.80	3	5	10	18	29	44	55	63
34	0.27	17.67	0.80	3	5	10	18	29	44	55	63
35	0.27	17.48	0.81	3	5	10	17	29	44	55	63
36	0.26	17.28	0.82	3	5	10	17	29	44	55	63
37	0.26	17.08	0.82	3	5	9	17	29	43	55	63
38	0.25	16.86	0.83	3	5	9	17	28	43	55	63
39	0.25	16.62	0.84	3	5	9	17	28	43	55	63
40	0.24	16.37	0.85	3	5	9	16	28	43	55	63
41	0.23	16.11	0.86	3	5	9	16	28	43	55	63
42	0.23	15.83	0.87	3	4	8	16	27	43	55	63
43	0.22	15.54	0.88	3	4	8	16	27	42	54	64
44	0.21	15.24	0.89	3	4	8	15	27	42	54	64
45	0.20	14.91	0.90	3	4	8	15	26	42	54	64
46	0.19	14.57	0.91	3	4	8	15	26	42	54	64
47	0.18	14.22	0.92	2	4	7	14	26	41	54	64
48	0.17	13.85	0.93	2	4	7	14	25	41	54	64
49	0.16	13.46	0.94	2	4	7	13	25	41	54	64
50	0.15	13.06	0.95	2	3	7	13	24	40	53	64
51	0.14	12.65	0.97	2	3	6	13	24	40	53	64
52	0.13	12.22	0.98	2	3	6	12	23	39	53	64

Table 5.5: Continued

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
53	0.12	11.78	0.99	2	3	6	12	22	39	52	64
54	0.10	11.32	1.00	2	3	6	11	22	38	52	64
55	0.09	10.86	1.02	2	3	5	11	21	37	52	63
56	0.08	10.39	1.03	2	3	5	10	20	37	51	63
57	0.06	9.92	1.04	2	2	5	10	20	36	51	63
58	0.05	9.44	1.05	2	2	5	9	19	35	50	63
59	0.03	8.97	1.07	1	2	4	9	18	34	49	62
60	0.02	8.49	1.08	1	2	4	8	17	33	49	62
61	0.00	8.02	1.09	1	2	4	8	17	32	48	62
62	-0.02	7.56	1.10	1	2	4	8	16	31	47	61
63	-0.03	7.11	1.10	1	2	3	7	15	30	46	61
64	-0.05	6.66	1.11	1	2	3	7	14	29	45	61
65	-0.07	6.23	1.11	1	2	3	6	13	28	44	60
66	-0.09	5.82	1.12	1	2	3	6	13	27	43	60
67	-0.11	5.43	1.12	1	1	3	5	12	26	42	59
68	-0.13	5.05	1.12	1	1	2	5	11	25	41	59
69	-0.15	4.70	1.11	1	1	2	5	10	23	40	58
70	-0.17	4.37	1.11	1	1	2	4	10	22	39	58
71	-0.20	4.06	1.10	1	1	2	4	9	21	38	57
72	-0.22	3.77	1.08	1	1	2	4	8	20	36	56
73	-0.24	3.50	1.07	1	1	2	3	8	18	35	55
74	-0.27	3.25	1.05	1	1	2	3	7	17	33	54
75	-0.29	3.02	1.02	1	1	2	3	7	16	31	52
76	-0.32	2.81	1.00	1	1	2	3	6	15	29	49
77	-0.35	2.63	0.97	1	1	1	3	6	13	26	46
78	-0.37	2.46	0.93	1	1	1	2	5	12	24	43
79	-0.40	2.30	0.90	1	1	1	2	5	11	22	39
80	-0.43	2.16	0.86	1	1	1	2	4	10	19	34
81	-0.46	2.04	0.82	1	1	1	2	4	9	17	30
82	-0.49	1.92	0.77	1	1	1	2	4	7	14	25
83	-0.52	1.80	0.73	1	1	1	2	3	6	12	20
84	-0.55	1.69	0.68	1	1	1	2	3	6	10	16
85+	-0.59	1.57	0.63	1	1	1	2	3	5	8	12

Table 5.6: Percentiles for Waist-Worn Accelerometer-Derived Minutes of Light Physical Activity in U.S. Males (*N*=3002).

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.79	364	0.29	203	237	296	364	436	503	543	570
21	0.79	365	0.28	204	238	297	365	437	503	544	571
22	0.79	366	0.28	204	238	298	366	438	504	545	572
23	0.79	367	0.28	205	239	298	367	439	505	546	573
24	0.79	368	0.28	206	240	299	368	439	506	547	574
25	0.79	369	0.28	207	241	300	369	440	507	548	574
26	0.79	369	0.28	208	242	301	369	441	508	548	575
27	0.79	370	0.28	208	242	301	370	442	508	549	576
28	0.79	371	0.28	209	243	302	371	442	509	549	576
29	0.79	371	0.28	210	244	303	371	443	509	550	577
30	0.79	372	0.28	210	244	303	372	443	510	550	577
31	0.79	372	0.28	211	245	304	372	443	510	550	577
32	0.79	373	0.28	211	245	304	373	444	510	550	577
33	0.79	373	0.28	212	245	304	373	444	510	550	577
34	0.79	373	0.28	212	246	305	373	444	510	550	577
35	0.79	373	0.28	212	246	305	373	444	510	550	576
36	0.79	373	0.28	212	246	305	373	443	509	549	576
37	0.79	372	0.28	212	246	304	372	443	508	549	575
38	0.79	372	0.28	212	246	304	372	442	508	548	574
39	0.79	371	0.28	212	246	304	371	442	507	547	573
40	0.79	371	0.27	212	245	303	371	441	506	546	572
41	0.79	370	0.27	211	245	303	370	440	505	544	570
42	0.79	369	0.27	211	244	302	369	439	503	543	569
43	0.79	368	0.27	210	243	301	368	437	502	541	567
44	0.79	367	0.27	210	243	300	367	436	500	540	566
45	0.79	365	0.27	209	242	299	365	435	499	538	564
46	0.79	364	0.28	208	241	298	364	433	497	536	562
47	0.79	363	0.28	207	240	297	363	431	495	534	560
48	0.79	361	0.28	206	238	295	361	429	493	532	558
49	0.79	359	0.28	204	237	294	359	427	491	530	555
50	0.79	357	0.28	203	236	292	357	425	489	527	553
51	0.79	355	0.28	202	234	290	355	423	486	525	550
52	0.79	353	0.28	200	232	288	353	420	483	522	547

Table 5.7: Continued

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
53	0.79	351	0.28	198	230	286	351	418	480	519	544
54	0.79	348	0.28	196	228	284	348	415	477	515	540
55	0.79	345	0.28	194	226	281	345	412	474	512	537
56	0.79	342	0.28	192	224	279	342	409	470	508	533
57	0.79	339	0.28	190	221	276	339	405	467	504	529
58	0.79	336	0.28	188	219	273	336	402	463	500	525
59	0.79	333	0.29	185	216	270	333	398	459	496	520
60	0.79	329	0.29	183	213	267	329	394	455	491	516
61	0.79	326	0.29	180	211	264	326	390	450	487	511
62	0.79	322	0.29	177	208	261	322	386	446	483	507
63	0.79	319	0.29	175	205	258	319	382	442	478	502
64	0.79	315	0.29	172	202	254	315	378	437	473	497
65	0.79	311	0.29	169	199	251	311	374	433	469	492
66	0.79	307	0.30	167	196	248	307	370	428	464	487
67	0.79	304	0.30	164	193	244	304	366	423	459	482
68	0.79	300	0.30	161	190	241	300	361	419	454	477
69	0.79	296	0.30	158	187	237	296	357	414	449	472
70	0.79	292	0.30	155	184	234	292	353	409	444	467
71	0.79	288	0.30	152	181	230	288	348	405	439	462
72	0.79	284	0.31	149	177	227	284	344	400	434	457
73	0.79	280	0.31	146	174	223	280	339	395	429	451
74	0.79	276	0.31	143	171	219	276	335	390	424	446
75	0.79	272	0.31	141	168	216	272	331	385	419	441
76	0.79	268	0.31	138	165	212	268	326	380	414	436
77	0.79	264	0.32	135	162	209	264	322	375	409	430
78	0.79	260	0.32	132	159	205	260	317	371	403	425
79	0.79	256	0.32	129	156	202	256	313	366	398	420
80	0.79	252	0.32	126	152	198	252	308	361	393	414
81	0.79	248	0.33	123	149	195	248	304	356	388	409
82	0.79	244	0.33	121	146	191	244	299	351	382	403
83	0.79	240	0.33	118	143	188	240	295	346	377	398
84	0.79	236	0.33	115	140	184	236	290	341	372	392
85+	0.79	232	0.33	112	137	181	232	285	336	366	387

Table 5.8: Percentiles for Waist-Worn Accelerometer-Derived Minutes of Light Physical Activity in U.S. Females (*N*=3091).

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
20	0.67	351	0.24	221	248	295	351	409	465	499	522
21	0.67	351	0.24	221	248	295	351	410	465	499	522
22	0.67	351	0.24	221	248	296	351	410	465	500	522
23	0.67	351	0.24	221	248	296	351	410	466	500	523
24	0.67	352	0.24	222	249	296	352	411	466	501	523
25	0.67	352	0.24	222	249	296	352	411	467	501	524
26	0.67	352	0.24	222	249	296	352	411	467	502	524
27	0.67	353	0.24	222	249	297	353	412	468	502	525
28	0.67	353	0.24	222	249	297	353	412	468	503	526
29	0.67	354	0.24	222	250	297	354	413	469	503	526
30	0.67	354	0.24	223	250	298	354	413	469	504	527
31	0.67	354	0.24	223	250	298	354	414	470	505	528
32	0.67	355	0.24	223	250	298	355	415	471	505	528
33	0.67	355	0.24	223	251	299	355	415	471	506	529
34	0.67	356	0.24	224	251	299	356	416	472	507	530
35	0.67	356	0.24	224	251	300	356	416	473	508	531
36	0.67	357	0.24	224	252	300	357	417	474	509	532
37	0.67	357	0.24	224	252	300	357	418	474	509	533
38	0.67	358	0.24	224	252	301	358	418	475	510	534
39	0.67	358	0.24	225	252	301	358	419	476	511	534
40	0.67	359	0.24	225	253	301	359	419	476	512	535
41	0.67	359	0.24	225	253	302	359	420	477	513	536
42	0.67	359	0.24	225	253	302	359	420	478	513	537
43	0.67	360	0.25	225	253	302	360	421	478	514	537
44	0.67	360	0.25	225	253	302	360	421	479	514	538
45	0.67	360	0.25	225	253	302	360	421	479	515	539
46	0.67	360	0.25	224	252	302	360	421	479	515	539
47	0.67	360	0.25	224	252	302	360	421	479	515	539
48	0.67	360	0.25	223	252	301	360	421	479	515	539
49	0.67	359	0.25	223	251	301	359	421	479	515	539
50	0.67	359	0.25	222	250	300	359	421	479	515	539
51	0.67	358	0.25	221	249	299	358	420	478	515	539
52	0.67	357	0.25	220	248	298	357	419	478	514	538

Table 5.8: Continued

				Percentiles							
Age	L	M	S	5	10	25	50	75	90	95	97
53	0.67	356	0.25	219	247	297	356	418	477	513	537
54	0.67	355	0.25	217	246	296	355	417	476	512	536
55	0.67	353	0.26	216	244	294	353	416	475	511	535
56	0.67	351	0.26	214	242	292	351	414	473	510	534
57	0.67	350	0.26	212	240	290	350	412	471	508	532
58	0.67	347	0.26	210	238	288	347	410	469	506	530
59	0.67	345	0.26	208	236	286	345	408	467	504	529
60	0.67	343	0.26	205	233	283	343	406	465	502	526
61	0.67	340	0.27	202	231	281	340	403	463	500	524
62	0.67	337	0.27	199	228	278	337	400	460	497	522
63	0.67	334	0.27	196	225	275	334	398	457	495	519
64	0.67	331	0.28	193	222	272	331	395	455	492	517
65	0.67	328	0.28	190	218	268	328	391	452	489	514
66	0.67	325	0.28	186	215	265	325	388	448	486	511
67	0.67	321	0.29	183	211	261	321	385	445	483	508
68	0.67	317	0.29	179	207	258	317	381	442	479	504
69	0.67	314	0.29	175	203	254	314	377	438	476	501
70	0.67	310	0.30	171	199	250	310	374	435	472	498
71	0.67	305	0.30	167	195	245	305	370	431	469	494
72	0.67	301	0.31	163	191	241	301	365	427	465	490
73	0.67	297	0.31	158	187	237	297	361	423	461	486
74	0.67	292	0.32	154	182	232	292	357	418	457	482
75	0.67	288	0.32	150	177	227	288	352	414	452	478
76	0.67	283	0.33	145	173	223	283	347	409	448	474
77	0.67	278	0.33	140	168	218	278	343	405	443	469
78	0.67	273	0.34	136	163	213	273	338	400	438	464
79	0.67	268	0.35	131	159	208	268	333	395	433	459
80	0.67	263	0.35	127	154	203	263	327	389	428	454
81	0.67	257	0.36	122	149	198	257	322	384	423	449
82	0.67	252	0.36	117	144	193	252	317	379	418	443
83	0.67	247	0.37	112	139	187	247	311	373	412	438
84	0.67	241	0.38	107	134	182	241	305	367	406	432
85+	0.67	236	0.39	103	129	177	236	300	362	401	427

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PART VI:

EXAMINING ASSOCIATIONS OF TOTAL ACTIVITY COUNTS AND PHYSICAL ACTIVITY INTENSITY WITH THE METABOLIC SYNDROME: A NOVEL USE OF STRUCTURAL EQUATION MODELING

Abstract

PURPOSE: To determine the relative contribution of accelerometer-derived measures of light- (LPA), moderate- (MPA), and vigorous- physical activity (VPA) intensities and total activity counts (TAC) in reduction of the prevalence of the metabolic syndrome. METHODS: Using 2003 – 2006 National Health and Nutrition Examination Survey (NHANES) data, the sample included adults ≥ 20 years of age, who participated in a fasting morning examination, were not pregnant or lactating, and had at least 4 days of ≥ 10 hours accelerometer wear time (n = 2238). The presence of the metabolic syndrome and associated risk factors was determined using established criteria. LPA, MPA, and VPA were defined as the number of minutes with counts between 100 - 2019, 2020 – 5998, and ≥ 5999, respectively. TAC represented the total activity counts acquired daily. LPA, MPA, VPA, and TAC were averaged across valid days to produce a daily mean. Structural equation modeling was used to fit three, gender specific models (1. MPA + VPA; 2. LPA + MPA + VPA; and 3. TAC) which examined the association of the metabolic syndrome and PA. All models controlled for relevant socio-demographic and genetic confounders. RESULTS: Across all models the PA indictors were found to have significant loadings on the latent construct PA. For both genders, the indirect association of the PA construct with the metabolic syndrome was the highest when PA was measured using TAC in model 3 (M: -1.14; F: -1.04) compared to MPA and VPA in model 1 (M: -0.88; F: -0.70) or LPA, MPA, and VPA in model 2 (M: -0.86; F: -0.84). Model 3 (TAC) also provided a better model fit than the two intensity-based models. CONCLUSIONS: The results of this study indicate a model with TAC provided the best fit for assessing the relationship between PA and the prevalence of the metabolic syndrome. Thus, TAC may be a better measure of PA when examining the association with the metabolic syndrome.

Introduction

The metabolic syndrome is a clustering of cardiometabolic risk factors that include central adiposity, hyperglycemia, elevated blood pressure, and dyslipidemia (elevated triglycerides and attenuated high-density lipoprotein cholesterol [HDL-C])[1]. Within the U.S., the metabolic syndrome is a growing public health concern; with the estimated prevalence in adults ranging from 22.9 to 34.9% depending on the metabolic syndrome definition used[1-3].

Physical activity (PA) is a modifiable behavior that has consistently demonstrated inverse associations with the metabolic syndrome[4-9]. The majority of this research, however, has relied on self-report measures of PA, which are subject to substantial bias that has been well documented in the PA Epidemiology literature[10-13]. In contrast, objective measures of PA, such as those derived from accelerometers, may provide increased precision and decreased bias when investigating the dose-response relationship and potential threshold effect of PA associated with the metabolic syndrome. However, there are a limited number of epidemiological studies that have assessed the relationship between the metabolic syndrome and objectively-measured PA[14-16]. Furthermore, these studies use different accelerometer-derived measures of PA, limiting the interpretability of results.

Specifically, Kim et al.[17] and Loprinzi et al.[18] examined the association between accelerometer-derived light-intensity PA (LPA) and the metabolic syndrome and found that individuals with higher levels of LPA were less likely to be classified with the metabolic syndrome, independent of moderate-to-vigorous-intensity PA (MVPA). In another study, Jansen et al.[14] explored the benefits of VPA and found that approximately 75 minutes/week of VPA provided a greater reduction (37.1%) in the prevalence of the metabolic syndrome than an equivalent volume (150 minutes/week) of MPA (15.5%). The benefits total volume, measured

as steps/day, was also examined by Sisson al.[16] who found that the prevalence of the metabolic syndrome decreased by 10% for every 1,000 steps accumulated daily.

While these studies provide evidence that all PA intensities have health benefits, there is also concern that accelerometer data reduction techniques may not provide accurate measurements of time spent in various intensity categories (*i.e.,* sedentary, LPA, MPA, and VPA)[19-22]. One way to circumvent these inaccuracies is to use the accelerometer-derived total activity counts per day (TAC), which is a more direct expression of what the monitor records. More importantly, TAC is a proxy for the total volume of PA as it incorporates all intensity categories and weights each minute according to the intensity of movement. Recent work by Wolff and colleagues (Part IV) demonstrated that TAC had stronger associations with cardiometabolic biomarkers (*i.e.*, blood pressure, body mass index, cholesterol, etc.) than accelerometer-derived minutes spent in MVPA bouts of 10 minutes or greater; suggesting that TAC is a more robust measure of PA.

In light of these results, it is necessary to determine whether TAC or another accelerometer-derived PA measure has the greatest contribution to reduction in the prevalence of the metabolic syndrome and its components. Structural equation modeling (SEM) is a novel statistical approach within the field of PA Epidemiology that allows researchers to determine the relative contribution of multiple PA measures to the reduction of disease[23]. In particular, SEM enables us to simultaneously analyze direct and indirect effects of factors known to influence the prevalence of the metabolic syndrome and its components. This provides an advantage over traditionally used regression models, which treat covariates as having a direct effect on the metabolic syndrome. Additionally, SEM allows for the comparison of multiple theoretical models that are well-specified and complex[23,24].

Thus, the purpose of this study was to use SEM to examine whether MPA+VPA, LPA+MPA+VPA, or TAC provides the best fit for assessing the relationship with the metabolic syndrome. This study also assessed the relative contribution of LPA, MPA, VPA, and TAC to the reduction in the prevalence of the metabolic syndrome and it's components. Emphasis was placed on determining whether TAC is a viable alternative to more traditional accelerometer-based measures of PA (*e.g.,* MVPA) when examining the reduction in the prevalence of the metabolic syndrome.

Methods

The present study used data from the 2003 – 2006 National Health and Nutrition Examination Survey (NHANES). The NHANES is a cross-sectional survey utilizing a complex, multistage probability design in order to obtain a representative sample of the non-institutionalized U.S. population[25]. The NHANES data are collected during an in-person home interview and a visit to a mobile examination center (MEC). The interview collects demographic, socioeconomic, and health-related information. The examination consists of laboratory tests and medical and physiological measurements.

For this study, the sample was limited to adults ≥ 20 years of age who participated in a fasting morning examination ($N = 4312$). Participants with less than four days of ≥ 10 hours of accelerometer wear time ($n = 1513$), pregnant or lactating women ($n = 146$), and individuals with missing data ($n = 415$) were excluded from the analysis, resulting in a final sample of ($n = 2238$). The original survey protocols were approved by National Center for Health Statistics ethics review board, and informed consent was obtained from all NHANES participants. The University of Tennessee institutional review board approved the use of NHANES data in this analysis.

The Metabolic Syndrome

The American Heart Association/National Heart Lung and Blood Institute (AHA/NHLBI)[26] guidelines were used to determine the presence or absence of the metabolic syndrome and its five underlying risk factors. Specifically, the metabolic syndrome was represented as a dichotomized measure which classified participants as having the metabolic syndrome if three or more of the following risk factors were present: (1) high waist circumference (≥ 102 cm for men and ≥ 88 cm for women); (2) elevated triglycerides (≥ 150 mg/dL or on drug treatment); (3) attenuated HDL-C (< 40 mg/dL for men and < 50 mg/dL for women, or on drug treatment); (4) elevated blood pressure (≥ 130 / ≥ 85 mmHg or on drug treatment); and (5) impaired fasting glucose (≥ 100 mg/dL or on drug treatment)[27]. The five underlying risk factors of the metabolic syndrome were also dichotomized based on the aforementioned criteria and were included as formative indicators (*i.e.,* direct effects) of the metabolic syndrome in the structural equation models.

Accelerometer data collection and analysis

Ambulatory individuals examined in the MEC were eligible participants for the accelerometer component. Eligible participants were instructed to wear an ActiGraph model 7164 accelerometer for seven days on their right hip during waking hours and to take it off for swimming or bathing[22]. Details of the accelerometer protocol can be found on the Centers for Disease Control and Prevention (CDC) website[28]. The ActiGraph model 7164 is a uniaxial accelerometer measuring vertical acceleration in one-minute epochs. The vertical accelerations obtained from the device are filtered, full-wave rectified, and integrated over time[29]; resulting in "activity counts per minute" which correspond to the intensity of ambulatory movement[30].

In this study, accelerometer data was analyzed using the SAS macro provided by the National Cancer Institute website[31]. Non-wear time was defined as ≥ 60 consecutive minutes with zero accelerometer counts, allowing up to two minutes with limited movement (< 100 counts per minute). Daily wear time was determined by subtracting non-wear time from 24 hours. A valid day was defined as a day with 10 or more hours of monitor wear[32]. Only participants with at least four days of valid monitor wear time were included in this analysis.

The variable total activity counts per day (TAC) was created by summing the counts accumulated on each valid day and averaging them over the total number of valid wear days. As TAC captured all counts accumulated during valid wear times it therefore included time spent in sedentary activity and all PA intensity sub-categories. Using thresholds described by Troiano[16], LPA was defined as the total number of 1-min epochs between 100 – 2019 counts while MPA and VPA were defined as the total number of 1-min epochs between 2020 – 5998 and ≥ 5999 counts, respectively. LPA, MPA, and VPA were averaged across all valid days.

Covariates

Several variables known to confound the relationship between PA and the metabolic syndrome, served as covariates in this study. Demographic covariates included: age (six categories representing 10 y age increments from 20 y to ≥ 70 y), race/ethnicity (non-Hispanic [NH] white, NH black, and Mexican American/Other), education (< 9^{th} grade, 9^{th} – 11^{th} grade, high school or GED, some college or Associates, and ≥ college graduate), and household income (eight categories starting from < $20,000, then $5,000 increments to ≥ $75,000). Family history of coronary heart disease (CHD) also served as a covariate in this analysis. Specifically, participants were classified as having a family history of CHD if they reported a parent and/or sibling had been told by a doctor they had CHD.

Statistical Analysis

Data were recoded and descriptive analyses were performed using SAS 9.2 (SAS Institute, Inc., Cary, NC). In addition, the SAS macro provided by the National Cancer Institute[7] was used to recode accelerometer-derived measures of PA. Descriptive analyses did not account for the complex sampling design of the NHANES in order to make comparisons to the results obtained from the structural equation modeling (SEM) analyses.

Specifically, SEM was performed using AMOS 20.0 (AMOS Development Corp., Meadville, PA), which is unable to take into account the NHANES sampling weights and sampling design variables that adjust for the complex sampling design. SEM is an advanced statistical technique which tests hypotheses about the relationships between observed (manifest) variables and latent constructs[33]. Latent constructs are comprised of multiple measures that are classified as being exogenous or endogenous. Exogenous variables are not dependent on any other variables and are therefore thought of as the independent variables. Endogenous variables are considered mediating or dependent variables as these constructs are dependent on at least one other construct. SEM simultaneously estimates the relationship between exogenous and endogenous latent constructs, the loadings of manifest variables onto each construct, and measurement and prediction error[23,33,34].

In the present analysis, SEM was used to test three hypothetical models that were stratified by gender and used various accelerometer-derived measures of PA to examine the association between the prevalence of the metabolic syndrome and PA. The dependent variable in these models was prevalence of the metabolic syndrome, which had five manifest variables (*e.g.,* waist circumference, blood pressure). The independent variable, accelerometer-derived PA, was measured continuously, with each model including different accelerometer-derived

measures of PA. In model 1, the PA latent construct was comprised of two manifest variables: accelerometer-derived minutes of MPA and VPA. Model 2 had the following three manifest variables loading onto the PA latent construct: accelerometer-derived minutes of LPA, MPA, and VPA. For model 3, TAC was the only manifest variable loading onto the PA latent construct.

Maximum likelihood estimation was used to estimate model parameters (*i.e.,* factor loadings and standardized regression weights). This estimation method is the most commonly used procedure in SEM as it is robust against moderate non-normality. Factor loadings were used to determine the relative contribution of each PA manifest variable in explaining the PA latent construct. A higher factor loading indicated a stronger contribution of the variable to the PA latent construct. Standardized regression weights or path weights assessed the standard deviation change in an outcome variable (*e.g.,* the metabolic syndrome) for every one standard deviation unit change in a predictor variable (*e.g.,* PA). As the metabolic syndrome variable and the five risk factors were dichotomized (0 = does not meet criteria, and 1 = meets criteria), the standard deviation represents the prevalence of the variable. Thus, multiplying the standard deviation of the outcome variable by its respective standardized path weight provided an estimate of the prevalence of the outcome variable for every standard deviation change in the predictor variable.

The fit of each model was also compared to determine which accelerometer model best explained the association between the reduction in the prevalence of the metabolic syndrome, the components of the metabolic syndrome, and PA. This analysis evaluated four different fit indices: chi-square (χ^2) to degrees of freedom (df) ratio (χ^2/df), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Akaike Information Criterion (AIC). The χ^2/df ratio assesses the fit of a model and the data, with ratios < 4 indicating

reasonable fit and < 2 suggesting very good fit. RMSEA indicates the fit of the model in the population's covariance matrix, with 0.05 considered to be a "close" fit, < 0.08 reflecting moderate fit, and >0.10 indicating unacceptable fit[35]. CFI compares the independence model (*i.e.,* worst possible fitting model) to the substantive model (*i.e.,* tested model), with values ≥ 0.90 indicating good fit[35]. AIC was used to compare the adequacy of the three models; with the smallest AIC representing the best model[36].

Results

Table 6.1 displays the demographic characteristics and prevalence estimates of the metabolic syndrome and its components by gender for subjects included in this study. A majority of participants were over 50 years of age, NH White, had attained a high school education/GED or greater, and reported an annual household income of $35,000 or greater. Several gender differences were also noted. In particular, females were more likely than males to report a family history of CHD (15.3 vs. 11.7%, $p = 0.013$) and had a higher prevalence of central adiposity (67.9 vs. 43.6; $p < 0.001$). Males had a higher prevalence of elevated triglycerides (36.3 vs. 28.0%; $p < 0.001$), attenuated HDL-C (57.3 vs. 27.3%; $p < 0.001$), impaired fasting glucose (47.5 vs. 36.5%; $p < 0.001$), and the metabolic syndrome (56.8 vs. 43.2%; $p < 0.001$) (Table 6.1). Physical activity also varied by gender (Table 6.2), with men found to accumulate significantly greater amounts of MPA (26.87 vs. 14.91; $p < 0.001$) and TAC (292749 vs. 229065; $p < 0.001$) compared to females. The accelerometer wear time was also found to be significantly higher in males (14.36 vs. 14.03; $p < 0.001$), however, no significant difference in LPA or VPA was found between genders.

Table 6.1: Characteristics of Participants by Gender

	Males		Females		
Characteristic	***n***	**Percent**	***n***	**Percent**	***p*-value**
Age (years)					0.136
20 – 29	147	12.7	117	10.9	
30 – 39	186	16.0	150	13.9	
40 – 49	207	17.8	214	19.9	
50 – 59	173	14.9	170	15.8	
60 – 69	203	17.5	221	20.5	
≥ 70	244	21.0	206	19.1	
Race/Ethnicity					0.233
NH white	629	54.2	581	53.9	
NH black	201	17.3	214	19.9	
Mexican American/Other	330	28.4	283	26.3	
Education					0.103
< 9^{th} grade	163	14.1	122	11.3	
9 – 11^{th} grade	155	13.4	123	11.4	
High school grad/GED	285	24.6	272	25.2	
Some college or AA	315	27.2	332	30.8	
≥ College graduate	242	20.9	229	21.2	
Household income					0.293
< $20K	208	17.9	232	21.5	
$20 – 24.9K	84	7.2	89	8.3	
$25 – 34.9K	168	14.5	156	14.5	
$35 – 44.9K	128	11.0	104	9.6	
$45 – 54.9K	124	10.7	117	10.9	
$55 – 64.9K	92	7.9	81	7.5	
$65 – 74.9K	83	7.2	59	5.5	
≥ $75K	273	23.5	240	22.3	
CHD Family History	136	11.7	165	15.3	0.013
Metabolic Syndrome Components					
Central Adiposity	506	43.6	732	67.9	<0.001
Elevated Blood Pressure	587	50.6	510	47.3	0.065
Elevated Triglycerides	421	36.3	302	28.0	<0.001
Attenuated HDL-C	665	57.3	294	27.3	<0.001
Impaired Fasting Glucose	551	47.5	393	36.5	<0.001
Metabolic Syndrome	541	56.8	412	43.2	< 0.001

Note: NH, non-Hispanic; AA, Associates of Arts; CHD, coronary heart disease; HDL-C, high density lipoprotein cholesterol.
**p*-values are based on a χ^2 test.

Table 6.2: Accelerometer-derived physical activity levels of male and female participants.

	Males		Females		
Physical Activity Variable	**Mean**	**SE**	**Mean**	**SE**	***P* value**
Light PA (min.)	345.49	3.21	338.30	2.95	0.10
Moderate PA (min.)	26.87	0.75	14.91	0.47	<0.001
Vigorous PA (min.)	0.85	0.09	0.62	0.08	0.06
Total Activity Counts	292740	4570	229065	3391	<0.001
Wear Time (hr/day)	14.36	0.06	14.03	0.05	<0.001

Note: Light, moderate, and vigorous intensity physical activity represent total daily non-bout minutes. SE, standard error; PA, physical activity; min., minutes; hr, hours.

Physical Activity Factor Loadings

Figures 6.1 – 6.3 display the three gender-specific structural equation models. For simplicity, covariate paths of age, race/ethnicity, socioeconomic status, and family history of CHD are not presented. For expanded models and standardized regression weights please refer to Appendices A and B. Across all models, the PA indictors had significant loadings on the latent construct PA. In model 1 (MPA+VPA) and model 2 (LPA+MPA+VPA), MPA had a high loading for both genders (Figures 6.1 – 6.2) with VPA having substantially lower loadings. LPA (model 2) had a high loading that was similar to MPA for males (0.51) but did not load as high for females (0.31) (Figure 6.2). For both males and females, TAC (Figure 6.3) had a high loading that was similar to MPA and male's LPA.

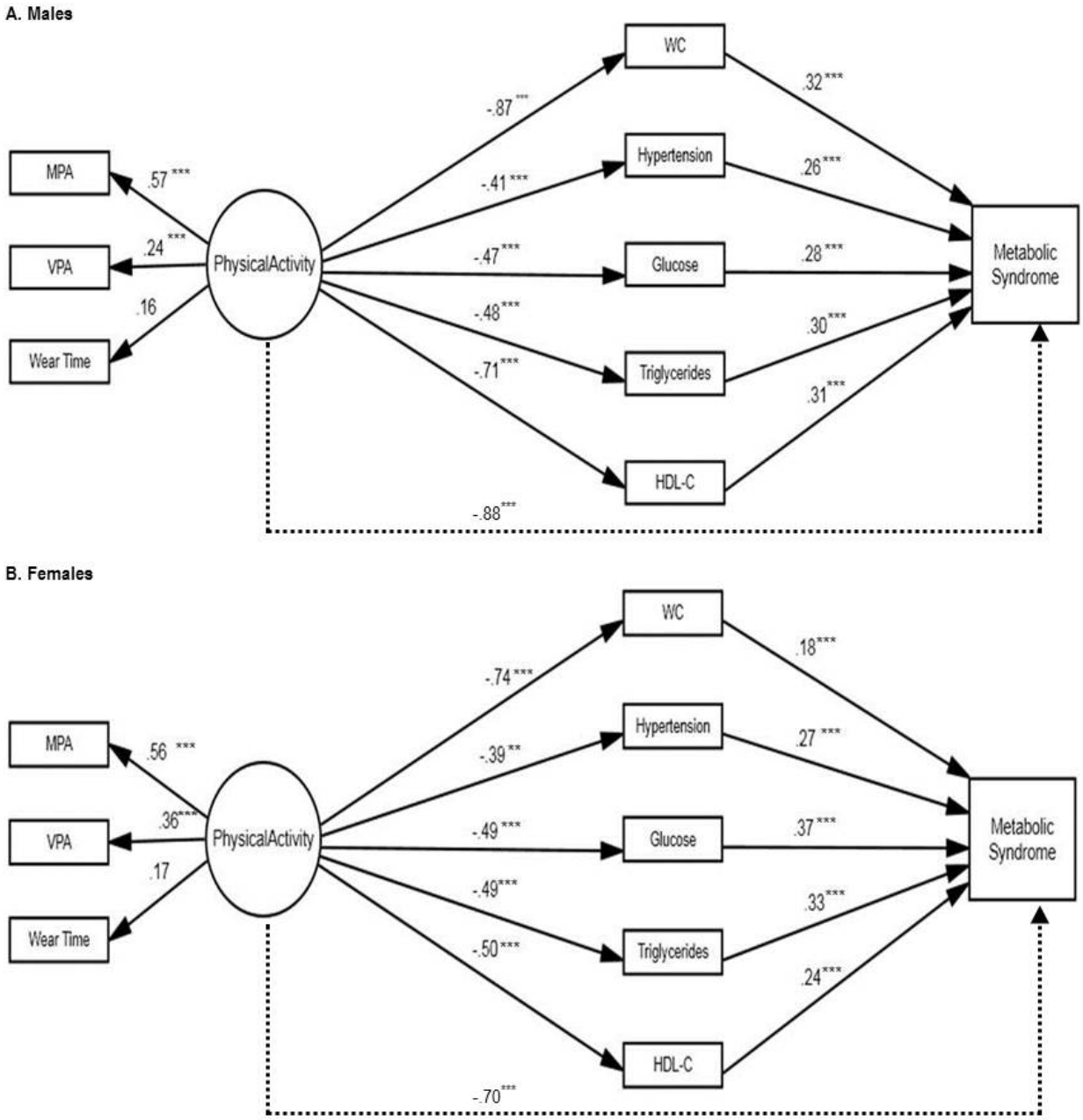

Figure 6.1: Model 1 of moderate and vigorous intensity physical activity and the metabolic syndrome in adult (A) Males and (B) Females, NHANES 2003 - 2006.

Note: Model fit (A): CMIN/DF=4.25, CFI = 0.95, RMSEA = 0.05, AIC = 324.59;
Model fit (B): CMIN/DF = 4.26, CFI = 0.96, RMSEA = 0.05, AIC = 325.27. Adjusted for age, race/ethnicity, socioeconomic status, and family history of coronary heart disease.
Abbreviations: MPA, moderate physical activity; VPA, vigorous physical activity; WC, waist circumference; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent construct; box indicates observed variable; straight line represents a direct effect; dashed line represents an indirect effect.

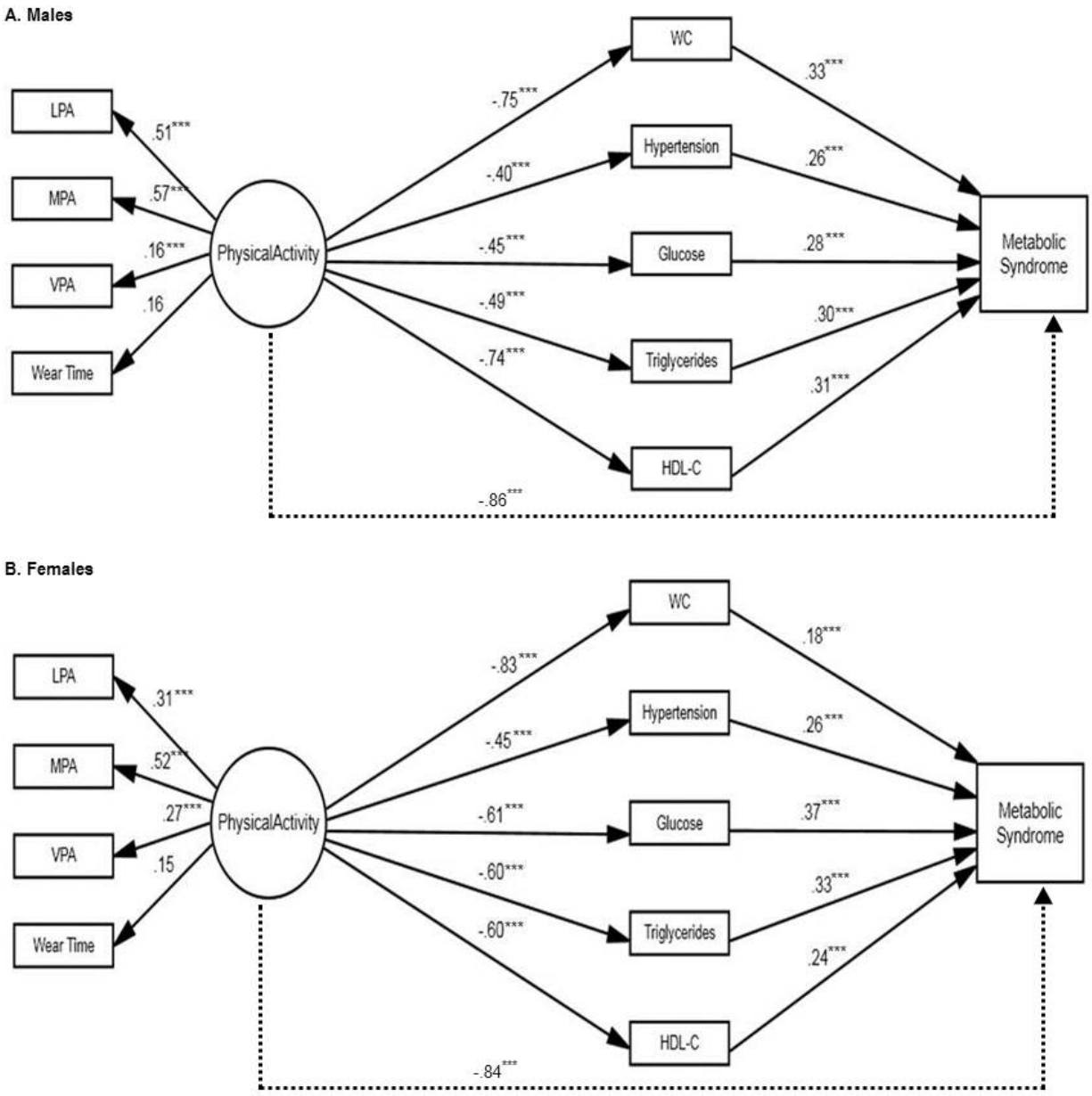

Figure 6.2: Model 2 of light, moderate, and vigorous intensity physical activity and the metabolic syndrome in adult (A) Males and (B) Females, NHANES 2003 - 2006.

Note: Model fit (A): CMIN/ CMIN/DF = 5.09, CFI = 0.93, RMSEA = 0.06, AIC = 431.72; Model fit (B): CMIN/DF = 4.57, CFI = 0.94, RMSEA = 0.06, AIC = 339.09. Adjusted for age, race/ethnicity, socioeconomic status, and family history of coronary heart disease.
Abbreviations: LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity; WC, waist circumference; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent construct; box indicates observed variable; straight line represents a direct effect; dashed line represents an indirect effect.

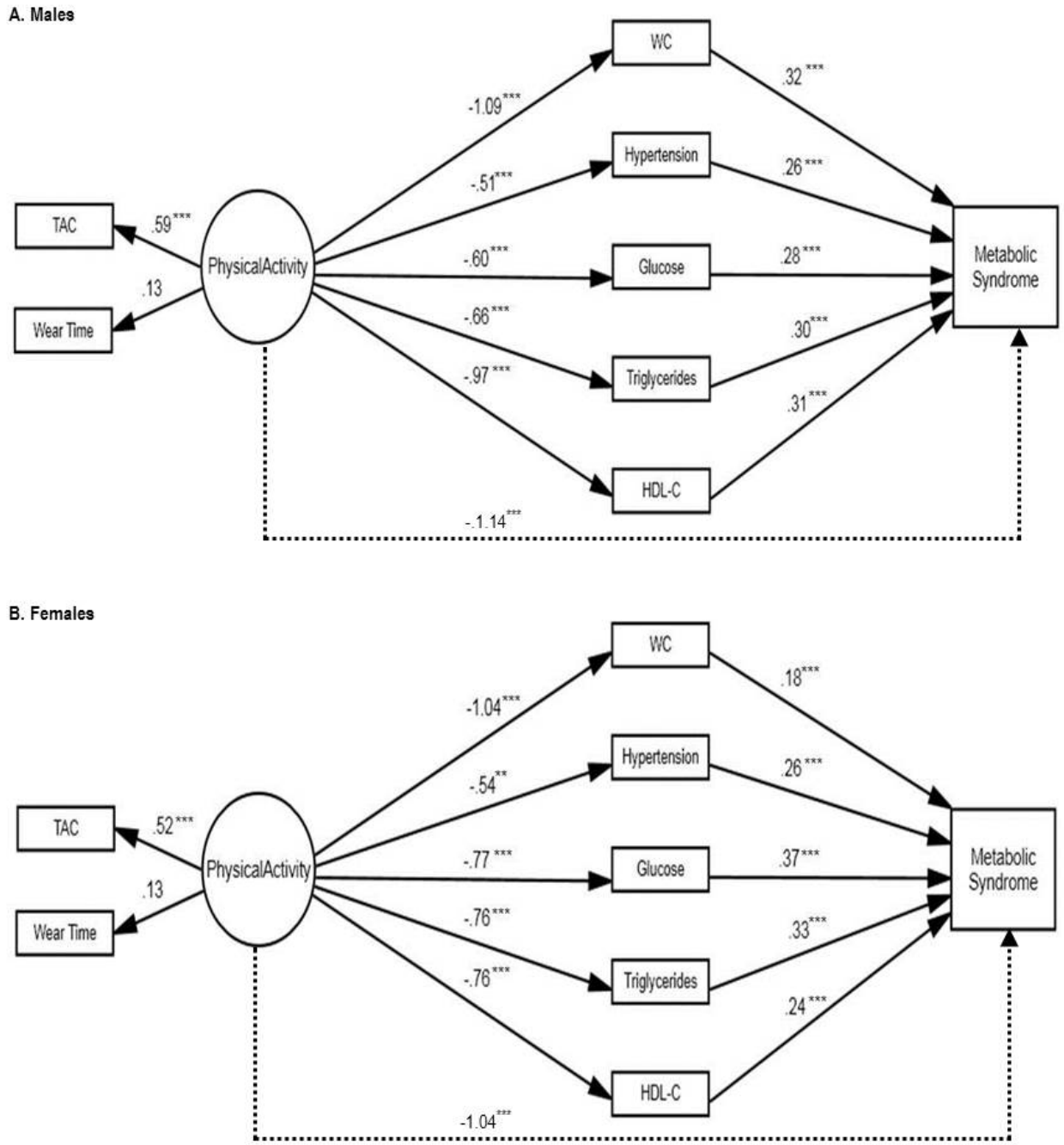

Figure 6.3: Model 3 of total activity counts and the metabolic syndrome in adult (A) Males and (B) Females, NHANES 2003 - 2006.

Note: Model fit (A): CMIN/DF = 3.67, CFI = 0.97, RMSEA = 0.05, AIC = 247.21;
Model fit (B): CMIN/DF = 3.70, CFI = 0.97, RMSEA = 0.05, AIC = 248.28. Adjusted for age, race/ethnicity, socioeconomic status, and family history of coronary heart disease.
Abbreviations: TAC, total activity counts; WC, waist circumference; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent construct; box indicates observed variable; straight line represents a direct effect; dashed line represents an indirect effect.

Association of Physical Activity with the Metabolic Syndrome Components

Table 6.3 summarizes the standardized path weights from PA to the metabolic syndrome and its components for each model by gender. These results indicate that for both genders, across the three models, there is a significant inverse association between PA and the components of the metabolic syndrome. Across all models, regardless of gender, PA had the greatest association with waist circumference (M: -0.75 to -1.09; F: -0.74 to -1.04) and had the least association with hypertension (M: -0.40 to -0.51; F: -0.39 to -0.54).

Several gender differences were also seen in the three models, with the association between PA and HDL-C found to be larger for men (-0.71 to -0.97) than women (-0.50 to -0.76). In model 1 (MPA+VPA) and model 2 (LPA+MPA+VPA), PA was more strongly associated with fasting glucose and triglycerides in women compared to men. Examining the paths of each model, it was also found that TAC had the greatest association with all five metabolic syndrome components (Table 6.3).

Association of the Metabolic Syndrome Components with the Metabolic Syndrome

Table 6.3 displays the standardized regression weights between all five components of the metabolic syndrome and the prevalence of the metabolic syndrome. As the prevalence of the metabolic syndrome was a formative indicator, the path weight of each metabolic syndrome risk factor to the prevalence of the metabolic syndrome varied little across models for each respective gender. For males, HDL-C (0.31) had the greatest association and hypertension (0.26) and had the least association with the risk of being classified with the metabolic syndrome. In females, fasting glucose (0.37) was found to have the strongest association and waist circumference the least association (0.18) with the prevalence of the metabolic syndrome.

Table 6.3: The association of physical activity intensity and volume with the risk of metabolic syndrome diagnosis: summary of factor loadings and standardized path weights for models 1 – 3 by gender.

	Model 1 (MPA + VPA)		**Model 2 (LPA + MPA + VPA)**		**Model 3 (TAC)**	
	Males	Females	Males	Females	Males	Females
PA Factor Loadings						
LPA	--	--	0.513***	0.305***	--	--
MPA	0.570***	0.558***	0.574***	0.518***	--	--
VPA	0.240***	0.363***	0.155***	0.267***	--	--
TAC	--	--	--	--	0.594***	0.519***
Wear Time	0.157	0.166	0.157	0.147	0.134	0.129
PA to MetS Risk Factors						
PA → WC	-0.871***	-0.740***	-0.755***	-0.826***	-1.093***	-1.038***
PA → Hypertension	-0.408***	-0.391***	-0.405***	-0.453***	-0.514**	-0.537**
PA → Glucose	-0.466***	-0.488***	-0.454***	-0.613***	-0.598***	-0.766***
PA → Triglycerides	-0.483***	-0.492***	-0.493***	-0.605***	-0.661***	-0.759***
PA → HDL-C	-0.712***	-0.498***	-0.744***	-0.602***	-0.968***	-0.761***
PA to MetS Diagnosis						
PA - -> MetS	-0.883***	-0.704***	-0.861***	-0.838***	-1.145***	-1.040***
MetS Risk Factors to MetS						
Hypertension → MetS	0.261***	0.267***	0.263***	0.265***	0.259***	0.264***
WC → MetS	0.324***	0.182***	0.327***	0.18***	0.322***	0.180***
Triglycerides → MetS	0.298***	0.333***	0.301***	0.331***	0.297***	0.329***
HDL-C → MetS	0.308***	0.239***	0.311***	0.237***	0.307***	0.237***
Glucose → MetS	0.280***	0.372***	0.283***	0.369***	0.279***	0.368***

Note: LPA, minutes of light intensity physical activity; MPA, minutes of moderate intensity physical activity; VPA, minutes of vigorous intensity physical activity; WC, waist circumference, HDL-C, high density lipoprotein cholesterol;
--, Not applicable as measure not included in model
→, Direct effect;
- ->, Indirect effect;
* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

Association of Physical Activity with the Metabolic Syndrome

For both genders, the indirect association of the PA construct with the metabolic syndrome was the highest when PA was measured using TAC in model 3 (M: -1.14; F: -1.04) compared to MPA and VPA in model 1 (M: -0.88; F: -0.70) or LPA, MPA, and VPA in model 2 (M: -0.86; F: -0.84) (Table 6.3). The reduction in the prevalence of the metabolic syndrome for a standard deviation increase in the PA indicator variables (*i.e.,* LPA, MPA, VPA, and TAC) is displayed in table 6.4. For an expanded table please refer to Appendix C. In models 1 and 2, increasing MPA by 6.1 - 6.8 minutes per day in males and 4.9 - 5.3 minutes per day in females was associated with a reduction in the prevalence of the metabolic syndrome of 3.4% and 2.5 - 3.0%, respectively. Increasing VPA, by 0.5 - 0.6 minutes per day in males and 0.6 - 0.7 minutes per day in females was associated with a 1.4 to 1.7% and 1.5 to 2.1% reduction in the metabolic syndrome, respectively. Every additional 22 minutes per day of LPA in females and 24 additional minutes per day in males was associated with a reduction in the prevalence of the metabolic syndrome of 1.9 and 3.2%, respectively. In model 3, the prevalence of the metabolic syndrome was reduced by 4.6% in females and 3.5% in males for an increase of 39,721 and 35,910 TAC, respectively.

Table 6.4: Reduction in metabolic syndrome prevalence with increased physical activity

	Model 1		Model 2		Model 3	
	SD_{PA}	**Δ MetS[a]**	**SD_{PA}**	**Δ MetS[a]**	**SD_{PA}**	**Δ MetS[a]**
Males						
MPA - -> MetS	6.8	-3.4%	6.1	-3.4%	--	--
VPA - -> MetS	0.6	-1.4%	0.5	-1.7%	--	--
LPA - -> MetS	--	--	24	-3.2%	--	--
TAC - -> MetS	--	--	--	--	39721	-4.6%
Females						
MPA - -> MetS	5.3	-2.5%	4.9	-3.0%	--	--
VPA - -> MetS	0.7	-1.5%	0.6	-2.1%	--	--
LPA - -> MetS	--	--	22.0	-1.9%	--	--
TAC - -> MetS	--	--	--	--	35910	-3.5%

Note: Δ, change; MetS; metabolic syndrome; SD_{PA}; standard deviation of the physical activity (PA) variable; MPA, moderate PA; VPA, vigorous PA; LPA, light PA; TAC, total activity counts.
[a]MetS change represents the percent change in the metabolic syndrome for every SD increase in the physical activity indicator variable.
--, Not applicable as measure is not included in model.

Model Fit of Physical Activity with the Metabolic Syndrome

The model fit for the three gender-specific structural equation models is presented in Table 6.4. All models displayed good fit, with CFIs ranging from 0.93 to 0.97 and the RMSEA at or above 0.05. The best fitting model for both genders, however, was model 3 (TAC) as the χ^2/DF ratio was lower than three and the AIC was substantially lower than the other two models. Model 1 (MPA + VPA) had the second best fit followed by model 3 (LPA + MPA + VPA).

Table 6.5: Fit indices of the final structural models

	Model 1 (MPA + VPA)	Model 2 (LPA + MPA + VPA)	Model 3 (TAC)
X^2/DF			
Males	4.25	5.09	3.67
Females	4.26	4.57	3.70
CFI			
Males	0.95	0.93	0.97
Females	0.96	0.94	0.97
RMSEA			
Males	0.05	0.06	0.05
Females	0.05	0.06	0.05
AIC			
Males	324.59	431.72	247.21
Females	325.27	399.09	248.28

Note: MPA, moderate physical activity; VPA, vigorous physical activity; LPA, light physical activity; TAC, total activity counts; X^2, chi-square; df, degrees of freedom, CMIN/DF, minimum chi-square; CFI, Comparative Fit Index; RMSEA, Root Mean Square Error of Approximation; AIC, Akaike Information Criterion.

Discussion

The present study highlights the utilitarian value of SEM in examining the relationship between PA and the prevalence of the metabolic syndrome. In particular, the results provide insight into the complex relationship between PA intensity and volume and the reduction of the prevalence of the metabolic syndrome. To our knowledge, this is the first study to determine the relative contributions of TAC and various intensities of PA to the prevalence of the metabolic syndrome and its underlying risk factors. The major finding was that a model with TAC provided the best fit for assessing the association between PA and the metabolic syndrome. In addition, the PA construct had stronger associations with the metabolic syndrome and its components when represented by TAC.

This finding is due in part to the measurement of PA in each model. In particular, TAC is a continuous measure that weights each minute according to the intensity of the movement. This

allows TAC to serve as a proxy for the total volume of PA while preserving the variability of the measure within a sample. In addition, TAC provides an alternative to traditional approaches to accelerometer data reduction as it avoids the pitfalls of misclassification error associated with these techniques.

While the TAC appears to be the best metric by which to estimate the association of PA with the metabolic syndrome, the results of this study indicate that both TAC and PA intensity subcategories are significantly associated with the metabolic syndrome. This is consistent with previous research that found LPA[17,37,38] and MVPA[14,37,39,40] both have a significant and independent contribution to the risk reduction of the metabolic syndrome. These results also support previous work of Wolff and colleagues, who demonstrated that TAC had stronger associations with cardiometabolic biomarkers (*i.e.*, blood pressure, body mass index, cholesterol, etc.) than accelerometer-derived minutes spent in MVPA bouts of 10 minutes or greater (Part IV).

The results of this study are also consistent with *2008 Physical Activity Guidelines Advisory Committee* (PAGAC) report[41]. In particular, the report proposes that minutes of VPA count twice as much as MPA and the health benefits derived from PA are likely accrued in proportion to intensity. In the present study, models 1 and 2 revealed that increasing VPA by less than a minute per day (0.5 - 0.7 minutes) was associated with a 1.4 - 2.1% drop in the prevalence of the metabolic syndrome. However, greater than 5-minutes of MPA per day was needed to produce a 2.5 - 3.5% reduction in the prevalence, respectively. The PAGAC report[41] also indicated that the total volume of activity is more closely related to health outcomes. Our findings revealed the importance of total volume as reflected in models 2 and 3. Specifically, model 2 demonstrated that increasing LPA by 22 minutes per day in women and 24 minutes per

day in men significantly reduced the prevalence of the metabolic syndrome by 1.9 and 3.2%, respectively. In addition, model 3 (TAC) was found to have the greatest association with the metabolic syndrome and its components as well as the best overall fit for capturing the relationship between the metabolic syndrome and PA.

While model 2 (LPA+MPA+VPA) and model 3 (TAC) reflected the total volume of PA, the results were not comparable, with model 2 performing the worst of the three models. One explanation is that the TAC metric included counts accrued in sedentary time, while model 2 (LPA + MPA + VPA) did not include a measure of sedentary time. However, the average daily counts accumulated due to sedentary behavior accounted for less than 2% of the daily TAC. A more plausible explanation is the cut-points for LPA (100 – 2019 counts/min) and MPA (2020 – 5998 counts/min), which may have resulted in misclassification of PA at both ends of the intensity spectrum. For example, one study found the total amount of time spent in MVPA, regardless of bout duration, was underestimated by 50% when using NHANES ActiGraph cut-points[19]. In another study, Lyden et. al[42] evaluated the ability of different regression equations for the ActiGraph, Actical, and RT_3 accelerometers to accurately classify time spent in PA intensity sub-categories and found none of the regression equations examined were able to correctly classify minutes spent in each intensity category. In particular, the misclassification error of these equations ranged from 8.9 - 34.3% for MPA and 28.2 - 54.5% for VPA. The authors noted that the misclassification error of MPA may be related to the insensitivity of the regression equations to distinguish LPA due to the high y-intercept of 2.6 METs. While regression equations with a lower y-intercept had increased sensitivity to LPA, they tended to underestimate MPA and VPA[42].

Due to this misclassification error, the PA estimates derived from cut-points vary widely. This was demonstrated by Loprinzi et al., using the NHANES data, who found the time spent in MVPA ranged from 17 to 59 minutes per day and the percentage meeting PA guidelines ranged from 6.2 – 59.3%, depending on the regression equation used[75]. Therefore, it is unclear which cut-point(s), if any, provide an accurate representation of the time spent in LPA, MPA, and VPA. This is a limitation to the present study as well as other studies using cut-points to classify the intensity of PA, as the misclassification error may affect the relationship with disease leading to conflicting results. In addition to the estimation error associated with cut-points derived from regression equations, the numerous cut-points also hinders the ability to draw comparisons between studies[76,77]. Freedson et al.[43] have therefore urged researchers to discontinue the development of cut-points to categorize accelerometer-derived PA and explore alternative accelerometer data reduction techniques.

There are two key strengths of the current study. The first is the use of accelerometers, an objective measure of PA, which improves the precision with which PA is measured. The second is the statistical approach utilized in this study. Specifically, SEM uses multiple, correlated measures to define a construct. This allowed for the inclusion of multiple PA intensity levels, which can't be modeled simultaneously in traditional regression due to violations of multicollinearity[33,44,45].

There are also several limitations of this study. Specifically, SEM was performed using AMOS 20.0, which is unable to account for complex sampling design inherent within the NHANES. Also, due to the cross-sectional design of this study, causality cannot be determined. Other health variables (*i.e.,* smoking, alcohol intake, poor diet) involved in the interplay between PA and the metabolic syndrome were not controlled for in this study. In particular, dietary

factors (*i.e.*, saturated fat levels, caloric intake) were not controlled for in this study due to the complexity of the dietary data file within the NHANES. It is also important to note that accelerometer counts are dependent on the characteristics of the PA monitor used. Therefore, counts obtained from different accelerometer brands are not comparable. However, the ActiGraph is the most common accelerometer used in PA research and has been shown to provide adequate reliability and validity of PA measurements across multiple generations of the device[46-49].

In summary, the results of this study indicate that both the intensity and volume of PA are significantly associated with the prevalence of the metabolic syndrome and its components. However, compared to models with intensity sub-categories, the TAC model resulted in a 1.8% and 2.0% greater reduction in the prevalence of the metabolic syndrome in men and women, respectively. More importantly, a model with TAC provided the best fit for assessing the relationship between PA and the prevalence of metabolic syndrome and its components. These findings suggest TAC may be a better measure of PA when examining the association with the metabolic syndrome. Future studies, however, should further explore this relationship using prospective study designs and different chronic disease states.

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PART VII

CONCLUSION

In order to explore the efficacy of TAC as a measure of PA, this dissertation used data from the 2003 - 2006 National Health and Nutrition Examination Survey to: 1) investigate whether TAC was more strongly associated with cardiometabolic biomarkers than minutes of moderate-to-vigorous PA (MVPA), 2) determine population-referenced TAC percentiles for the U.S. population, and 3) determine which accelerometer-derived measure(s) of PA intensity and volume provided the best fit for assessing the association with the metabolic syndrome.

The findings presented within this dissertation provide insights into the objective measurement of physical activity (PA) using accelerometers, and has implications for epidemiological and public health research. Specifically, this dissertation explored the efficacy of total activity counts (TAC) as a measure of PA using data from the 2003 – 2006 National Health and Nutrition Examination Survey. The first study (Part IV) investigated whether TAC was more strongly associated with cardiometabolic biomarkers than minutes of moderate-to-vigorous PA (MVPA). The major finding this study was that TAC consistently displayed stronger associations with cardiometabolic biomarkers than MVPA accumulated in ≥ 10 minute bouts. More importantly, TAC remained more strongly associated with biomarkers after adjustment for BMI.

The second study (Part V) determined the population-referenced TAC percentiles for the U.S. population. The findings presented within this section describe the population-referenced TAC percentiles, for the U.S. adult population. These percentiles provide PA and public health researchers with a measure of the total volume of PA that can be expressed relative to others of the same age and gender (*i.e.,* as percentiles). Furthermore, these results provide insights into how the intensity and volume of PA changes throughout adulthood.

The third study (Part VI) determined which accelerometer-derived measure(s) of PA intensity and volume provided the best fit for assessing the association with the metabolic syndrome. The results of this study highlight the utilitarian value of SEM in examining the relationship between PA and the prevalence of the metabolic syndrome. In particular, the results provide insight into the complex relationship between PA intensity and volume and the reduction of the prevalence of the metabolic syndrome. To our knowledge, this is the first study to determine the relative contributions of TAC and various intensities of PA to the prevalence of the metabolic syndrome and its underlying risk factors. The major finding was that a model with TAC provided the best fit for assessing the association between PA and the metabolic syndrome. In addition, the PA construct had stronger associations with the metabolic syndrome and its components when represented by TAC.

The findings of these three studies reveal that TAC may be the best metric by which to estimate the association with cardiometabolic disease states. The advantage to using TAC is that it incorporates all intensities and patterns of PA. Additionally, TAC is the most direct expression of what the accelerometer measures. If a uniform method of accelerometer data collection were established, TAC could be reported as a standardized measure. This could allow for comparisons to be drawn across studies using waist-worn ActiGraph accelerometers. TAC could also complement other measures of PA as it still allows reporting of other PA variables (*e.g.,* minutes spent in various intensity categories). Future research, however, should explore this relationship with other chronic diseases and should utilize a prospective design in order to establish causality.

APPENDICES

Appendix A:

Fully Depicted Models

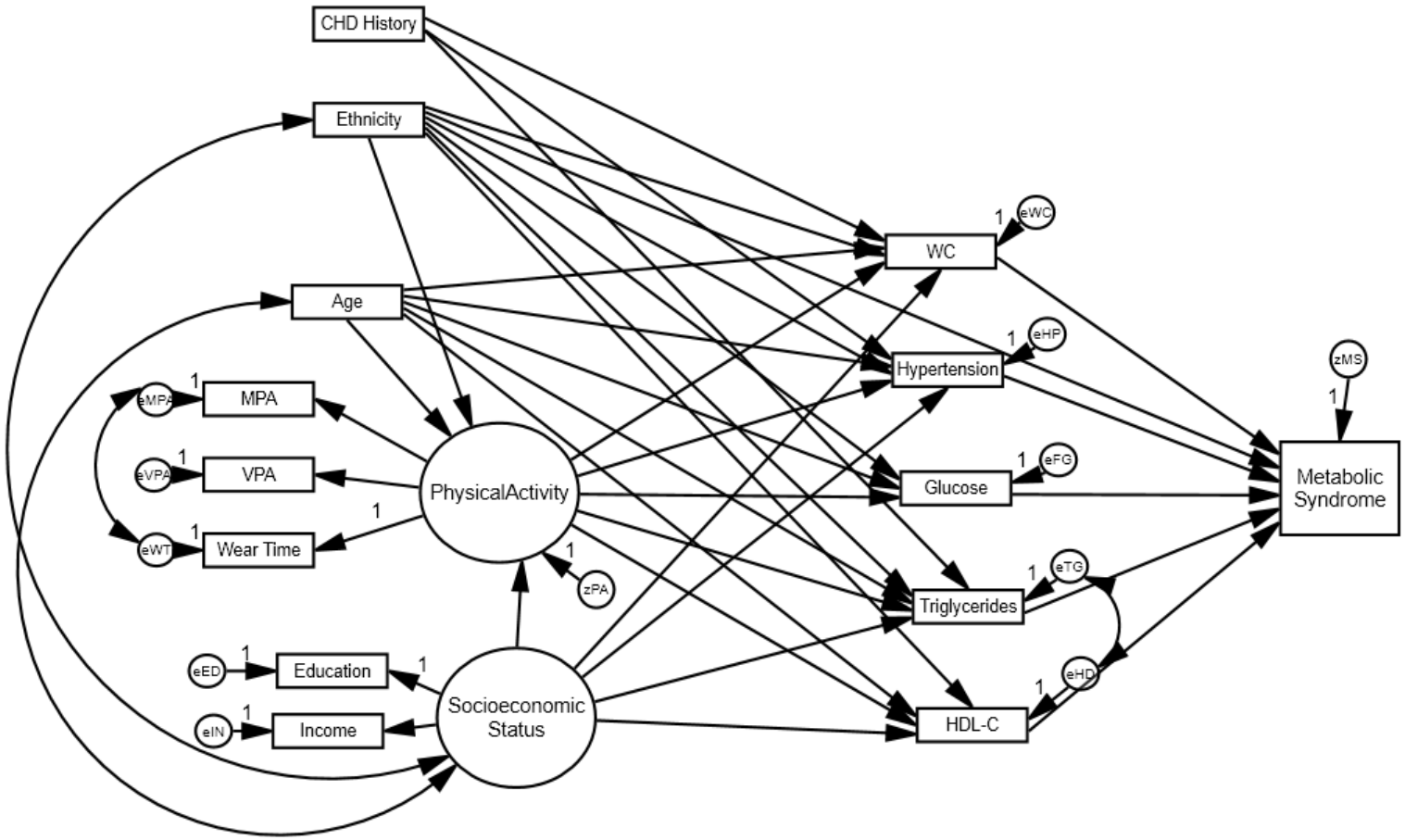

Figure A.1: Final model 1 depicting the relationship between moderate- and vigorous- intensity physical activity and the metabolic syndrome, NHANES 2003-2006.

Note: MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent, unobservable constructs; box indicates observed variable; straight line with one arrowhead denotes a direct effect; curved line with a double-headed arrow indicates a correlation; e, error of manifest variable; z, residual error term of latent construct.

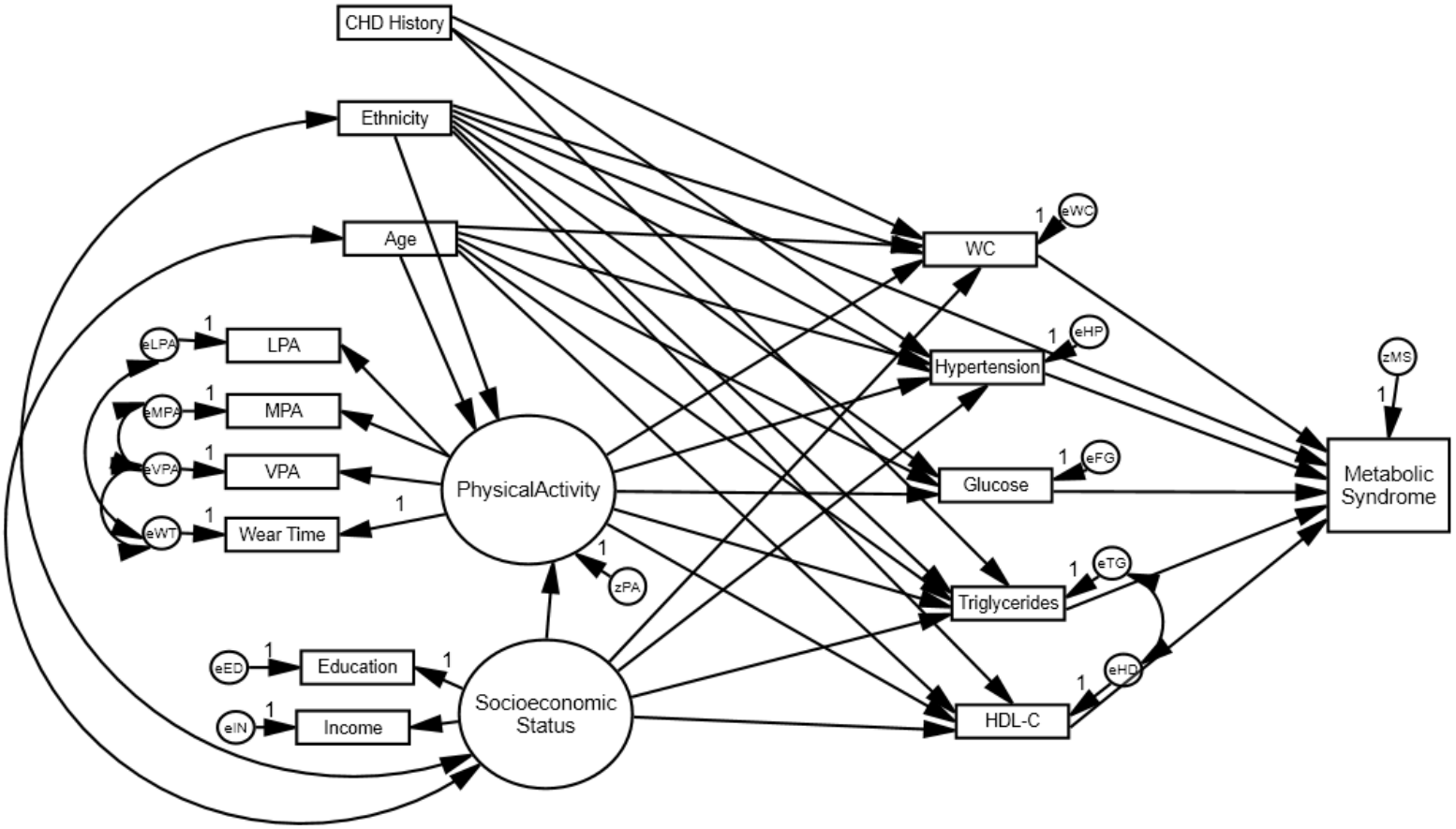

Figure A.2: Final model 2 depicting the relationship between light-, moderate- and vigorous- intensity physical activity and the metabolic syndrome, NHANES 2003-2006.

Note: LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent, unobservable constructs; box indicates observed variable; straight line with one arrowhead denotes a direct effect; curved line with a double-headed arrow indicates a correlation; e, error of manifest variable; z, residual error term of latent construct.

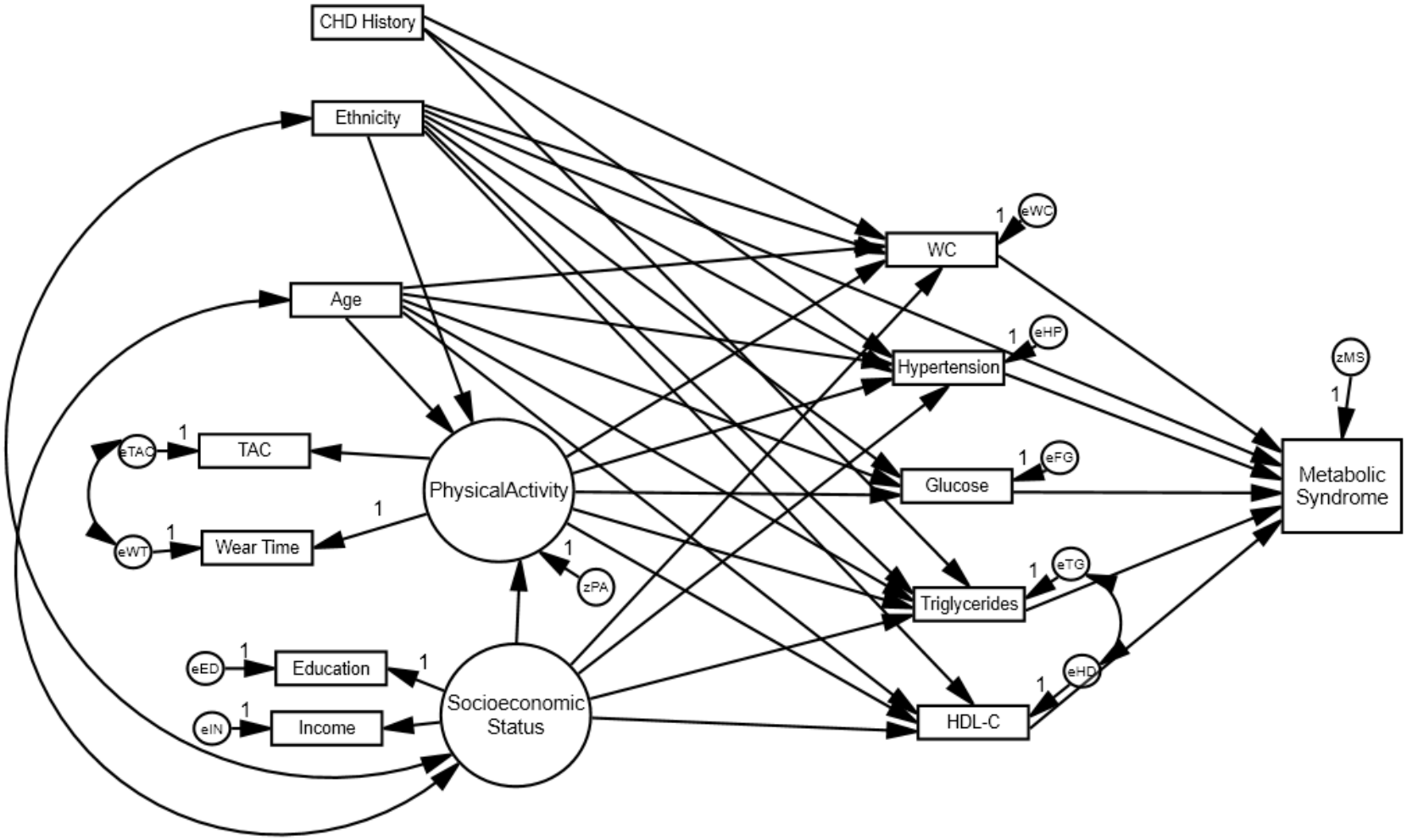

Figure A.3: Final model 3 depicting relationship between total activity counts and the metabolic syndrome, NHANES 2003-2006.

Note: TAC, total activity counts; HDL-C, high density lipoprotein cholesterol. Ellipse indicates latent, unobservable constructs; box indicates observed variable; straight line with one arrowhead denotes a direct effect; curved line with a double-headed arrow indicates a correlation; e, error of manifest variable; z, residual error term of latent construct.

Appendix B:

Standardized Parameter Estimates of Final Models

Table B.1: Model 1 standardized weights for the full structural model of relationships among moderate and vigorous physical activity and the metabolic syndrome

Path	Males	Females
Age → Physical Activity	-0.763***	-0.505***
Age → Hypertension	0.097	0.321***
Age → WC	-0.533***	-0.222***
Age → Triglycerides	-0.357***	-0.116*
Age → HDL-C	-0.613***	-0.388***
Age → Glucose	-0.116	-0.022
SES → Education	0.764	0.738
SES → Income	0.553***	0.572***
SES → Physical Activity	0.11	0.392***
SES → Hypertension	-0.019	0.092
SES → WC	0.143*	0.142
SES → Triglycerides	0.024	0.044
SES → HDL-C	-0.081	-0.006
Ethnicity → Physical Activity	0.153**	0.049
Ethnicity → Hypertension	0.013	0.044
Ethnicity → WC	0.02	0.087
Ethnicity → Triglycerides	0.099*	0.013
Ethnicity → HDL-C	0.02	0.017
Ethnicity → Glucose	0.086*	0.068*
Ethnicity → Metabolic Syndrome	0.004	-0.019
CHD History → Hypertension	-0.022	0.016
CHD History → WC	0.04	0.082**
CHD History → Triglycerides	0.064*	0.053
Physical Activity → MPA	0.57***	0.558***
Physical Activity → VPA	0.24***	0.363***
Physical Activity → Wear Time	0.157	0.166
Physical Activity → Hypertension	-0.408***	-0.391***
Physical Activity → WC	-0.871***	-0.74***
Physical Activity → Triglycerides	-0.483***	-0.492***
Physical Activity → HDL-C	-0.712***	-0.498***
Physical Activity → Glucose	-0.466***	-0.488***
Hypertension → Metabolic Syndrome	0.261***	0.267***
WC → Metabolic Syndrome	0.324***	0.182***
Triglycerides → Metabolic Syndrome	0.298***	0.333***
HDL-C → Metabolic Syndrome	0.308***	0.239***
Glucose → Metabolic Syndrome	0.28***	0.372***

Note: WC, waist circumference, HDL-C, high density lipoprotein cholesterol; CHD, coronary heart disease; MPA, minutes of moderate intensity physical activity; VPA, minutes of vigorous intensity physical activity

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

Table B.2: Model 2 standardized weights for the full structural model of relationships among light, moderate, and vigorous physical activity and the metabolic syndrome

Path	Males	Females
Age → Physical Activity	-0.796***	-0.678***
Age → Hypertension	0.088	0.212***
Age → WC	-0.476***	-0.407***
Age → Triglycerides	-0.381***	-0.279***
Age → HDL-C	-0.657***	-0.544***
Age → Glucose	-0.095	-0.177*
SES → Education	0.817	0.747
SES → Income	0.514***	0.565***
SES → Physical Activity	-0.143*	0.254**
SES → Hypertension	-0.117**	0.056
SES → WC	-0.084	0.062
SES → Triglycerides	-0.103*	0.002
SES → HDL-C	-0.258***	-0.05
Ethnicity → Physical Activity	0.151**	0.106
Ethnicity → Hypertension	0.015	0.073
Ethnicity → WC	-0.01	0.137*
Ethnicity → Triglycerides	0.098*	0.051
Ethnicity → HDL-C	0.029	0.055
Ethnicity → Glucose	0.133***	0.124***
Ethnicity → Metabolic Syndrome	0.004	-0.019
CHD History → Hypertension	-0.024	0.013
CHD History → WC	0.038	0.075**
CHD History → Triglycerides	0.063*	0.049
Physical Activity → LPA	0.513***	0.305***
Physical Activity → MPA	0.574***	0.518***
Physical Activity → VPA	0.155***	0.267***
Physical Activity → Wear Time	0.157	0.147
Physical Activity → Hypertension	-0.405***	-0.453***
Physical Activity → WC	-0.755***	-0.826***
Physical Activity → Triglycerides	-0.493***	-0.605***
Physical Activity → HDL-C	-0.744***	-0.602***
Physical Activity → Glucose	-0.454***	-0.613***
Hypertension → Metabolic Syndrome	0.263***	0.265***
WC → Metabolic Syndrome	0.327***	0.18***
Triglycerides → Metabolic Syndrome	0.301***	0.331***
HDL-C → Metabolic Syndrome	0.311***	0.237***
Glucose → Metabolic Syndrome	0.283***	0.369***

Note: WC, waist circumference, HDL-C, high density lipoprotein cholesterol; CHD, coronary heart disease; LPA, minutes of light intensity physical activity; MPA, minutes of moderate intensity physical activity; VPA, minutes of vigorous intensity physical activity

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

Table B.3: Model 3 standardized weights for full structural model of relationships among total activity counts and the metabolic syndrome

Standardized Estimates	**Males**	**Females**
Age → Physical Activity	-0.871***	-0.774***
Age → Hypertension	-0.038	0.104
Age → WC	-0.823***	-0.649***
Age → Triglycerides	-0.565***	-0.456***
Age → HDL-C	-0.91***	-0.725***
Age → Glucose	-0.261*	-0.355**
SES → Education	0.79	0.751***
SES → Income	0.534***	0.562
SES → Physical Activity	-0.052	0.211**
SES → Hypertension	-0.085	0.054
SES → WC	-0.018	0.074
SES → Triglycerides	-0.065	0.008
SES → HDL-C	-0.207***	-0.042
Ethnicity → Physical Activity	0.166**	0.098
Ethnicity → Hypertension	0.039	0.078
Ethnicity → WC	0.064	0.153
Ethnicity → Triglycerides	0.134**	0.061
Ethnicity → HDL-C	0.074	0.067
Ethnicity → Glucose	0.149***	0.132**
Ethnicity → Metabolic Syndrome	0.004	-0.019
CHD History → Hypertension	-0.023	0.013
CHD History → WC	0.038	0.075**
CHD History → Triglycerides	0.064*	0.049
Physical Activity → TAC	0.594***	0.519***
Physical Activity → Wear Time	0.134	0.129***
Physical Activity → Hypertension	-0.514**	-0.537**
Physical Activity → WC	-1.093***	-1.038***
Physical Activity → Triglycerides	-0.661***	-0.759***
Physical Activity → HDL-C	-0.968***	-0.761***
Physical Activity → Glucose	-0.598***	-0.766***
Hypertension → Metabolic Syndrome	0.259***	0.264***
WC → Metabolic Syndrome	0.322***	0.18***
Triglycerides → Metabolic Syndrome	0.297***	0.329***
HDL-C → Metabolic Syndrome	0.307***	0.237***
Glucose → Metabolic Syndrome	0.279***	0.368***

Note: WC, waist circumference, HDL-C, high density lipoprotein cholesterol; CHD, coronary heart disease; TAC, total activity counts.

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

Appendix C

Summary of the Reduction in Metabolic Syndrome Prevalence with Increased Physical Activity

Table C.1: Change in the prevalence of the metabolic syndrome & its risk factors related to physical activity for females.

	Model 1 (MPA + VPA)			Model 2 (LPA + MPA + VPA)			Model 3(TAC)		
	Beta	**SD_{PA}**	**% Change**	**Beta**	**SD_{PA}**	**%Change**	**Beta**	**SD_{PA}**	**% Change**
MPA to Risk Factors									
MPA → WC	-0.417	0.053	-0.079	-0.487	0.049	-0.093	--	--	--
MPA → Hypertension	-0.220	0.053	-0.040	-0.267	0.049	-0.048	--	--	--
MPA → Glucose	-0.275	0.053	-0.047	-0.361	0.049	-0.065	--	--	--
MPA → Triglycerides	-0.335	0.053	-0.064	-0.442	0.049	-0.084	--	--	--
MPA → HDL-C	-0.340	0.053	-0.065	-0.417	0.049	-0.079	--	--	--
VPA to Risk Factors									
VPA → WC	-0.269	0.007	-0.051	-0.342	0.006	-0.065	--	--	--
VPA → Hypertension	-0.142	0.007	-0.026	-0.186	0.006	-0.033	--	--	--
VPA → Glucose	-0.177	0.007	-0.030	-0.252	0.006	-0.045	--	--	--
VPA → Triglycerides	-0.218	0.007	-0.041	-0.283	0.006	-0.054	--	--	--
VPA → HDL-C	-0.219	0.007	-0.042	-0.282	0.006	-0.054	--	--	--
LPA to Risk Factors									
LPA → WC	--	--	--	-0.398	0.220	-0.076	--	--	--
LPA → Hypertension	--	--	--	-0.218	0.220	-0.039	--	--	--
LPA → Glucose	--	--	--	-0.295	0.220	-0.053	--	--	--
LPA → Triglycerides	--	--	--	-0.328	0.220	-0.062	--	--	--
LPA → HDL-C	--	--	--	-0.326	0.220	-0.062	--	--	--
TAC to Risk Factors									
TAC → WC	--	--	--	--	--	--	-0.568	359	-0.108
TAC → Hypertension	--	--	--	--	--	--	-0.294	359	-0.053
TAC → Glucose	--	--	--	--	--	--	-0.419	359	-0.075
TAC → Triglycerides	--	--	--	--	--	--	-0.395	359	-0.075
TAC → HDL-C	--	--	--	--	--	--	-0.378	359	-0.072
PA Measure to MetS									
LPA - -> MetS	--	--	--	-0.305	0.220	-0.019	--	--	--
MPA - -> MetS	-0.414	0.053	-0.025	-0.498	0.049	-0.030	--	--	--
VPA - -> MetS	-0.252	0.007	-0.015	-0.351	0.006	-0.021	--	--	--
TAC - -> MetS	--	--	--	--	--	--	-0.570	359	-0.035
PA Construct to MetS	-0.740	1	-0.043	-0.838	1	0.051	-1.040	1	-0.063

Note: %, percent; SD_{PA}; standard deviation of physical activity variable; WC, waist circumference; HDL-C, high density lipoprotein cholesterol; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; LPA, light intensity physical activity; TAC, total activity counts; MetS; the metabolic syndrome; --, Not applicable as measure is not included in model. →, Direct effect; - ->, Indirect effect.

Table C.2: Change in the prevalence of the metabolic syndrome & its risk factors related to physical activity for males.

	Model 1(MPA + VPA)			Model 2 (LPA + MPA + VPA)			Model 3 (TAC)		
	Beta	**SD_{PA}**	**% Change**	**Beta**	**SD_{PA}**	**% Change**	**Beta**	**SD_{PA}**	**% Change**
MPA to Risk Factors									
MPA → WC	-0.512	0.068	-0.082	-0.461	0.061	-0.069	--	--	--
MPA → Hypertension	-0.240	0.068	-0.036	-0.247	0.061	-0.035	--	--	--
MPA → Glucose	-0.274	0.068	-0.038	-0.277	0.061	-0.039	--	--	--
MPA → Triglycerides	-0.402	0.068	-0.064	-0.423	0.061	-0.063	--	--	--
MPA → HDL-C	-0.499	0.068	-0.080	-0.535	0.061	-0.086	--	--	--
VPA to Risk Factors									
VPA → WC	-0.209	0.0056	-0.033	-0.228	0.0052	-0.034	--	--	--
VPA → Hypertension	-0.098	0.0056	-0.015	-0.122	0.0052	-0.017	--	--	--
VPA → Glucose	-0.112	0.0056	-0.016	-0.137	0.0052	-0.019	--	--	--
VPA → Triglycerides	-0.166	0.0056	-0.027	-0.18	0.0052	-0.027	--	--	--
VPA → HDL-C	-0.205	0.0056	-0.033	-0.246	0.0052	-0.039	--	--	--
LPA to Risk Factors									
LPA → WC	--	--	--	-0.428	0.240	-0.064	--	--	--
LPA → Hypertension	--	--	--	-0.23	0.240	-0.032	--	--	--
LPA → Glucose	--	--	--	-0.258	0.240	-0.036	--	--	--
LPA → Triglycerides	--	--	--	-0.388	0.240	-0.058	--	--	--
LPA → HDL-C	--	--	--	-0.494	0.240	-0.079	--	--	--
TAC to Risk Factors									
TAC → WC	--	--	--	--	--	--	-0.684	397	-0.109
TAC → Hypertension	--	--	--	--	--	--	-0.322	397	-0.048
TAC → Glucose	--	--	--	--	--	--	-0.374	397	-0.052
TAC → Triglycerides	--	--	--	--	--	--	-0.570	397	-0.091
TAC → HDL-C	--	--	--	--	--	--	-0.713	397	-0.114
PA Measure to MetS									
LPA - -> MetS	--	--	--	-0.486	0.240	-0.032	--	--	--
MPA - -> MetS	-0.518	0.068	-0.034	-0.52	0.061	-0.034	--	--	--
VPA - -> MetS	-0.211	0.0056	-0.014	-0.26	0.005	-0.017	--	--	--
TAC - -> MetS	--	--	--	--	--	--	-0.707	397	-0.046
PA Construct to MetS	-0.883	1	-0.057	-0.861	1	-0.056	-1.145	1	-0.074

Note: %, percent; SD_{PA}; standard deviation of physical activity variable; WC, waist circumference; HDL-C, high density lipoprotein cholesterol; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; LPA, light intensity physical activity; TAC, total activity counts; MetS; the metabolic syndrome; --, Not applicable as measure is not included in model. →, Direct effect; - ->, Indirect effect.

VITA

Dana Lizbeth Wolff was born on March 28, 1987 in Mineola, New York. Shortly after her birth her parents moved to Chesapeake, Virginia where Dana lived throughout her childhood. In 2005 Dana graduated from Hickory High School and enrolled at Elon University where she obtained a Bachelor of Science degree in Exercise Science with a minor in Public Health Studies in 2009. Immediately following completion of her Bachelor's, Dana enrolled at The University of Tennessee where she completed Master's Degree in Exercise Physiology with a concentration in Epidemiology. Dana continued at the University of Tennessee to pursue a Doctor of Philosophy degree in Kinesiology and Sports Studies with a concentration in Physical Activity Epidemiology. While working on her degree, Dana received the University of Tennessee's ESPN Fellowship award and Andy Kozar Graduate Research Scholarship Award.