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Current public health guidelines for physical activity (PA) were primarily formulated using evidence collected from a series of prospective cohort epidemiological investigations that measured self-reported PA. In light of this observation, and the known discordance between self-reported and objectively-monitored PA, it remains common for researchers to assess compliance to current PA guidelines (≥ 150 minutes/week of an equivalent combination of moderate- and vigorous-intensity PA [MV2PA]) using objective-monitoring methods such as accelerometer-determined PA. However, investigations seeking to calibrate accelerometer-determined PA against self-reported compliance to current PA guidelines are scant within the extant literature. Calibration of objective-monitoring methods, such as accelerometer-determined PA, may prove fruitful in mitigating the discordance between self-reported and accelerometer-determined PA, while also providing compliance estimates for PA that better reflect a population's associated health risks. Therefore, the purpose of this study was to identify optimal accelerometer-determined thresholds of MV2PA that correspond to 150 minutes/week of self-reported MV2PA outlined in the current 2008 Physical Activity Guidelines for Americans (PAGA). This study was a secondary analysis of 4,784 adults (18-64 years) from the 2003-2006 NHANES who provided ≥ 4 valid days of accelerometer data. Receiver operating characteristic (ROC) curves were used to identify accelerometer-determined thresholds of weekly MV2PA corresponding to self-reported compliance to the 2008 PAGA. MV2PA in modified 10-minute bouts and total MV2PA were significant predictors of self-reported compliance to the 2008 PAGA (both $p < 0.001$). Optimal thresholds of accelerometer-determined MV2PA predicting self-reported compliance to the 2008 PAGA were 13.00 ± 1.69 minutes/week in modified 10-minute bouts and 122.30 ± 4.62 minutes/week in total (no bout requirement). However, levels of sensitivity and specificity associated with ROC curve analyses were low (all < 70%). Construct validity analyses revealed that self-reported compliance to the 2008 PAGA was only favorably associated with one cardiometabolic biomarker (glycated hemoglobin, $p = 0.003$). Conversely, compliance to the 2008 PAGA assessed using the newly identified accelerometer-determined MV2PA threshold in modified 10-minute bouts (≥ 13.0 minutes/week of MV2PA) was favorably associated with 5 biomarkers (glycated hemoglobin, high-density lipoprotein [HDL], systolic blood pressure [SBP], waist circumference, and body mass index [BMI]; all $p < 0.05$) and 2 chronic diseases (hypertension and obesity; all $p < 0.01$). Similarly, compliance to the 2008 PAGA assessed via total accelerometer-determined MV2PA (≥ 122.3 minutes/week of MV2PA; no bout requirement) was favorably associated with 6 biomarkers (glycated hemoglobin, fasting plasma glucose, triglycerides, SBP, waist circumference, and BMI; all $p < 0.05$) and 4 chronic diseases (hypertension, obesity, impaired fasting glucose, and diabetes mellitus; all $p < 0.05$). However, follow-up analyses using different activity counts/minute cut-points produced a wide range of optimal thresholds for MV2PA in 10-minute bouts (0.03 to 58.8 minutes/week) and in total (22.5 to 166.7 minutes/week). Although accelerometer-determined MV2PA was significantly related to self-reported compliance to the 2008 PAGA, the strength of this relationship was weak. Absolute estimates of weekly accelerometer-determined MV2PA corresponding to self-reported compliance to the 2008 PAGA were significantly less than the 150 minutes/week minimum criteria. Construct validity analyses indicated that compliance to the 2008 PAGA, as assessed using the newly identified accelerometer-determined MV2PA thresholds, was more strongly related to various anthropometric and cardiometabolic constructs than self-reported compliance. Future epidemiological and clinical research is needed to aid the development of PA guidelines informed by accelerometer-determined estimates of PA.

Identifying Threshold Values of Accelerometer-Determined Moderate-to-Vigorous Physical Activity that Correspond to Self-Reported Compliance to the 2008 Physical Activity Guidelines for Americans: National Health and Nutrition Examination Survey 2003-2006

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Julie A. Brier, Author

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Chapter 1. Introduction

Background and Significance

The concept of promoting optimal health by engaging in physical activity (PA) is by no means novel. Teachings that focused on PA for health improvement can be traced back to as early as 600 B.C., with evidence of PA's benefits enforced through visual results, inspirational concepts, and wisdom, rather than controlled empirical science (Blair & Morris, 2009). Over the past 50 years, a strong body of observational research has demonstrated that higher levels of habitual PA are associated with decreased risks for chronic disease morbidity and mortality (Blair & Morris, 2009; Haskell, 2012; Physical Activity Guidelines Advisory Committee, 2008). Additionally, regular PA is positively associated with improvements in health-related quality of life (Bize, Johnson, & Plotnikoff, 2007; Choi et al., 2013; Döring, de Munter, & Rasmussen, 2015).

The vast majority of scientific evidence used to describe the associations between PA and a variety of health-related outcomes was primarily derived using self-report PA assessment methods, such as questionnaires, logs, recalls, and diaries (Haskell, 2012). More recently, a variety of objective PA assessment methods have been developed and implemented widely within public health research (Freedson, Bowles, Troiano, & Haskell, 2012). Examples of such objective methodologies include, but are not limited to, pedometers, global positioning system devices, and specialized accelerometers designed to measure PA. In particular, accelerometers have been used extensively to estimate time spent in different intensities of PA throughout the day (Haskell, 2012). However, accelerometers are presently limited in their ability to capture other characteristics of PA, including activity type, location, or context. Regardless, it is important to acknowledge that both self-report and objective PA assessment methods have strengths and weaknesses that researchers need to understand when comparing and interpreting such measurement modalities (Troiano & Dodd, 2008).

Debates regarding the appropriate frequency, intensity, and types of PA needed to effectively stave off chronic disease and significantly improve health continue to occur as the body of evidence linking PA with positive health benefits grows. According to the 2008 Physical Activity Guidelines for Americans (PAGA), healthy adults should accumulate at least two-and-a-half hours (150 minutes) of weekly moderate-intensity or one hour and fifteen minutes (75 minutes) of weekly vigorous-intensity aerobic PA (in ≥ 10-minute bouts) or an equivalent combination of the two (U.S. Department of Health and Human Services, 2008). Additionally, the 2008 PAGA calls for engagement in muscle-strengthening activities that are moderate or high intensity and involve all major muscle groups on 2 or more days of the week. Current evidence supports the 2008 PAGA recommendation, as a combination of aerobic and muscle-strengthening activities appear to provide health benefits beyond those attained by either modality alone (Church et al., 2010; Slentz et al., 1985; Willis et al., 2012).

The 2008 PAGA recommendation for aerobic activity, in terms of the prescribed amount and intensity level, is associated with significant and substantial reductions in all-cause mortality risk among adults (Physical Activity Guidelines Advisory Committee, 2008). Although the recommended amount and intensity of aerobic PA outlined in the 2008 PAGA has been shown to provide substantial health benefits, fewer than 10% of United States (U.S.) adults are currently meeting these guidelines as measured objectively via accelerometer (Troiano et al., 2008; Tucker, Welk, & Beyler, 2011). In contrast to such objective assessments, recent data from the Behavioral Risk Factor Surveillance System (BRFSS) indicates that approximately 52% of U.S. adults are compliant with the 2008 PAGA as measured by subjective self-report methods (Centers for Disease Control and Prevention, 2013).

The above illustrated discrepancy in compliance estimates (> 40% difference) to the 2008 PAGA is directly related to the large magnitudes of difference in PA estimates (i.e., minutes/week of moderate-to-vigorous PA [MVPA], minutes/week of an equivalent combination of moderate- and vigorous-intensity PA [MV2PA]) often observed between self-report and objective assessment methodologies (Schuna, Johnson, & Tudor-Locke, 2013; Tucker et al., 2011). Such discrepancies between different assessment methods lead to logical questions such as: 1) which PA compliance estimates are correct? those obtained by self-report or those from objective methods? 2) why are there such large discrepancies in PA estimates between self-report and objective methods? and 3) might a combination of self-report and objective methods be more appropriate for assessing compliance to PA guidelines? Despite such questions and the observed discrepancies between self-report and objective PA assessments, these methods typically yield qualitatively similar results in terms of associations between their outputs (e.g., minutes/week of MVPA) and different theoretical constructs PA is related to (Troiano et al., 2008). That said, some evidence does indicate that objective measurements of PA are more strongly related to a variety of biological health constructs than self-reported PA (Atienza et al., 2011).

As the science of measuring PA continues to evolve, refinements to PA guidelines, including updates to the 2008 PAGA, will likely occur in tandem with improvements in our understanding of the relationships between PA and health. The last 15 years have been marked by a substantial shift in methodology preference regarding PA assessment (Troiano, McClain, Brychta, & Chen, 2014), as objective measures have replaced subjective self-reports as the predominant PA assessment method of choice. Despite this shift in preference toward objective PA assessments, it is important to remember that the vast majority of empirical evidence underpinning the 2008 PAGA was derived using self-report PA assessments (Physical Activity Guidelines Advisory Committee, 2008). This presents a dilemma when trying to interpret compliance to PA guidelines using objective PA assessments like accelerometry, as we are essentially comparing *apples to oranges* for lack of a better analogy. As such, to appropriately measure compliance to PA guidelines using objective PA assessment methodologies, future guidelines should be formulated using epidemiological evidence that links objectively measured PA with various health-related outcomes. As an alternative in the interim, investigators can seek to calibrate objective PA assessment methods against self-reported compliance to PA guidelines in an effort to more appropriately reflect a given group's health risk in relation to PA behavior. A detailed review regarding the topics of self-reported and objectively measured PA follows in the subsequent chapters.

Rationale

Despite several investigations examining the relationships between self-reported and accelerometer-determined PA using data collected from the National Health and Nutrition Examination Survey (NHANES; Schuna et al., 2013; Troiano et al., 2008; Tucker et al., 2011), there has yet to be any published research attempting to identify levels of accelerometer-determined MV2PA that correspond to self-reported compliance to the 2008 PAGA (≥ 150 minutes/week of MV2PA). To this end, our objective herein was to conduct analyses combining data from the 2003-2006 NHANES PA monitor (PAM) and PA questionnaire (PAQ) components to identify appropriate accelerometer-determined MV2PA thresholds that correspond to self-reported compliance to the 2008 PAGA. We believe that the identification of the aforementioned accelerometer-determined thresholds will aid public health and surveillance research efforts in two ways: 1) allow researchers to quantify accelerometer-determined compliance estimates to PA guidelines that are consistent with estimates likely to be obtained using subjective self-report methods, and 2) spur future development of PA guidelines that are based on epidemiological data illustrating the dose-response relationship between objectively monitored PA and a variety of chronic disease outcomes.

Specific Aims and Hypotheses

This research project was defined in terms of three specific aims and their associated hypotheses.

Aim #1. To calculate thresholds of accelerometer-determined MV2PA that correspond to self-reported compliance to the 2008 PAGA.

Hypothesis specific to aim #1. Our central hypothesis was that optimal accelerometer-determined MV2PA thresholds (minutes/week) corresponding to self-reported compliance to the 2008 PAGA would be of a substantially lower absolute magnitude than the self-reported MV2PA requirement of ≥ 150 minutes/week.

Aim #2. To evaluate the classification accuracy and construct validity of optimal accelerometer-determined MV2PA thresholds corresponding to self-reported compliance to the 2008 PAGA.

Hypothesis specific to aim #2. Our secondary hypothesis was that using the optimal accelerometer-determined MV2PA threshold (calibrated against self-reported compliance to the 2008 PAGA) to assess compliance to the 2008 PAGA would result in acceptable levels of classification accuracy relative to self-reported compliance estimates. Moreover, we hypothesized that relationships for accelerometer-determined and self-reported compliance to the 2008 PAGA with health-related anthropometric and cardiometabolic biomarkers would be similar.

Aim #3. To analyze the effect of different MVPA activity count cut-points on threshold values of accelerometer-determined MV2PA that correspond to self-reported compliance to the 2008 PAGA.

Hypothesis specific to aim #3. Our tertiary hypothesis was that identified accelerometer-determined MV2PA thresholds corresponding to self-reported compliance to the 2008 PAGA would significantly vary as a function of the

MVPA activity count cut-points used to define accelerometer-determined MV2PA.

Assumptions and Limitations

Assumptions. We assumed that all leisure time PAs assessed by the NHANES PAQ were of at least a moderate-intensity when quantifying self-reported compliance to the 2008 PAGA. Although we cannot empirically demonstrate that each activity elicited moderate or vigorous metabolic intensities, data from the Compendium of Physical Activities suggests that the reported activities included in these calculations are of at least a moderate intensity (Ainsworth et al., 2011; Ainsworth et al., 1993; Ainsworth et al., 2000). We also assumed that the PAQ used in NHANES would provide compliance estimates that were consistent with the broad array of self-report assessments available for use. This may not be a tenable assumption. However, we compared the estimated self-reported compliance estimates derived from the NHANES PAQ to data collected from other surveillance systems (e.g., BRFSS) to evaluate whether or not this was a plausible assumption.

Limitations. Limitations of this study included the use of a data source that is nearly 10 years-old. However, this represents the largest and most comprehensive data set containing combined assessments of accelerometer-determined and self-reported PA. Also, the use of self-report as the criterion measure may seem tenuous due to its limited reliability as demonstrated in some empirical investigations (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012). However, self-reported PA is clearly related to health outcomes given the wealth of evidence from previous studies examining such relationships (Physical Activity Guidelines Advisory Committee, 2008). In addition, there is no universal consensus as to how waist-worn accelerometer data should be processed while generating accelerometer-determined estimates of PA. To ensure comparability of our results, the procedures we have utilized are consistent with analyses conducted using NHANES accelerometer data previously described in several published reports (Schuna et al., 2013; Troiano et al., 2008; Tucker et al., 2011).

Definition of Terms

The following list contains operationalized definitions for a variety of terms used consistently herein:

- *Physical Activity*
    - Any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008) .
- *Physical Fitness*
    - A set of attributes that people have or achieve. Being physically fit has been defined as "the ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies," (Caspersen, Powell, & Christenson, 1985).

- *Exercise*
    - A subcategory of PA that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective (Caspersen et al., 1985).
- *Metabolic Equivalent*
    - A metabolic equivalent, or MET, is the rate of energy expenditure while sitting at rest. It is taken by convention to be an oxygen uptake of 3.5 milliliters per kilogram of body mass per minute. Physical activities frequently are classified by their intensity, using the MET as a reference (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008).
- *Moderate-Intensity Physical Activity*
    - On an absolute scale, moderate-intensity refers to activity that is performed at 3.0–5.9 times the intensity of rest. On a scale relative to an individual's personal capacity, moderate-intensity activity is usually a 5 or 6 on a scale of 0–10 (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008).

- *Vigorous-Intensity Physical Activity*
    - On an absolute scale, vigorous-intensity refers to activity that is performed at 6.0 or more times the intensity of rest for adults and 7.0 or more times for children and youth. On a scale relative to an individual's personal capacity, vigorous-intensity activity is usually a 7 or 8 on a scale of 0–10 (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008).
- *Acceleration*
    - Acceleration is the change in velocity with respect to time. Acceleration is usually quantified in terms of gravitational units (g; 1 g = 9.8 $m \cdot s^{-2}$). Because acceleration is proportional to the net external force involved, and therefore more directly reflective of energy costs, measuring PA using acceleration is preferred to using speed (Chen & Bassett, 2005).
- *Accelerometer*
    - A device or sensor that measures the proper acceleration of objects and quantifies them in motion along reference axes (Chen & Bassett, 2005). When attached to the body of a human participant, if the participant is at rest, the accelerometer measures the participant's orientation relative to the gravitational vector; if the

participant is moving, the accelerometer measures a combination of the participant’s orientation and acceleration (Xiao et al., 2016).

- *Accelerometry*
    - The collection of accelerometer data used to derive velocity and displacement information by integrating accelerometer data with respect to time (Chen & Bassett, 2005).

Chapter 2. Literature Review

Benefits of Physical Activity on Overall Health and Wellbeing

Engagement in regular PA as a means to promote healthy living and prevent chronic disease is recognized as an important public health strategy (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008). Insufficient amounts of PA or planned exercise are associated with increased risks for a variety of chronic diseases including, but not limited to, cardiovascular disease (CVD), diabetes, and obesity. Although causal links between PA and any given disease can be difficult to delineate, the extant literature has consistently demonstrated that regular PA decreases mortality risk (e.g., CVD, all-cause) and increases life expectancy (≈ 2-4 years) after controlling for known predictors of chronic disease such as body mass index (BMI), race/ethnicity, smoking status, and self-reported health (Blair & Morris, 2009; Brown et al., 2012; Landi et al., 2010; Lee et al., 2012; Reimers, Knapp, & Reimers, 2012; Schmid, Ricci, & Leitzmann, 2015).

PA can take many forms and occur in a variety of domains. From a historical perspective, societal roles for PA and exercise have evolved over time due to changes in cultural norms, various socioeconomic factors, and the built-environment (Booth et al., 2001). As an example, substantial changes in population levels of occupational PA among Americans have been observed over the past 50 years due to a redistribution of the workforce (Church et al., 2011). This workforce redistribution has been characterized by large reductions in the number of individuals employed in active manufacturing and agricultural jobs, which has been matched by concomitant increases in the number of individuals working in less active service-sector jobs.

Investigating how to increase intensity and duration of PA are of vital importance because there is a greater improvement in measurable health benefits (i.e., improvements in CVD-related biomarkers) equated with engaging in longer, more intense bouts of exercise than engaging in shorter, less intense bouts (Loprinzi, Lee, & Cardinal, 2013). Put simply, some PA is better than no activity, however, more PA is better (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008). Overall, the current body of scientific evidence strongly suggests that individuals who are not participating in any type of daily or recreational PA would benefit from increasing their PA to help counter the influence of the sedentary environment and appropriately balance utilization of energy in the body (Wolff-Hughes, Fitzhugh, Bassett, & Churilla, 2015).

Physical Activity Assessment in Adults

Human movement as a global construct can be categorized in two ways: 1) PA (a behavior) or 2) energy expenditure (Lamonte & Ainsworth, 2001). The construct of concern here is PA and the means by which it is assessed and interpreted. There are a variety of different assessment methods, both subjective and objective, that have been developed as a means to measure PA in humans. Subjective methods of PA assessment typically allow an individual to self-report their own PA habits while objective assessments are comprised of unbiased methods which do not rely on individual perceptions when estimating PA levels

(Dale, Welk, & Matthews, 2002). Generally speaking, subjective PA assessments have typically been comprised of PA logs, recalls, and questionnaires (Ainsworth, 2010). These subjective methods can provide opportunities to estimate the frequency, intensity, duration, and type of self-reported PA over the past day, week, month, or year. In contrast, objective assessments of PA can take many diverse forms and include methods such as accelerometry, pedometry, direct observation, heart rate monitoring, and global positioning systems (Ainsworth, 2010). Similar to subjective methods of PA assessment, the aforementioned objective methods can be employed for monitoring durations from 1 day to 1 year depending on need and available resources.

The abovementioned PA assessment methods are by no means exhaustive, but denote the majority of methods commonly used in currently published research (Ainsworth, 2010). It is important to recognize that although accelerometers are consistently utilized throughout the PA assessment literature and touted as advanced technology, there is no gold-standard objective wearable monitor (Ainsworth, Cahalin, Buman, & Ross, 2015). The appropriate selection of an optimal PA assessment method can be difficult given there are a multitude of factors that impact whether or not the method is applicable for a given instance or situation (Pettee Gabriel, Morrow, & Woolsey, 2012). Some of these factors include monetary costs, time and personnel availability for deployment, likelihood and magnitude of measurement error, level of measurement precision, and the appropriateness for a selected target population (Ainsworth et al., 2015). Because it is difficult to assess the frequency, intensity, duration, type, and context of PA using any single measurement instrument, it has been suggested that a combination of subjective and objective assessment methods may provide the most comprehensive picture when attempting to measure and characterize PA behaviors (Ainsworth, 2010; Haskell, 2012). However, it is important to recognize that all PA assessment methods, both subjective and objective, have inherent strengths and weaknesses which will be discussed in the following sections.

Subjective physical activity assessment methods.

Physical activity records and logs. PA records, which include written diaries, record books, or recorded dictations, are methods by which detailed accounts of activities completed within a given time frame are self-recorded by an individual (Ainsworth, 2010). These methods are useful for identifying the type, duration, and frequency of PA and are typically scored using the Compendium of Physical Activities which provides estimates of the absolute intensity (i.e., metabolic equivalents [METs]) associated with each activity (Ainsworth et al., 2011; Ainsworth et al., 1993; Ainsworth et al., 2000).

PA logs are similar to PA records but are typically modified so that a participant must document the types and durations of activities performed during specific time blocks throughout the day (Ainsworth, 2010). For example, the Bouchard PA log requires respondents to identify their activity in 15-minute bouts and provides an intensity scale ranging from 1 to 9 representing sleeping at the lowest intensity to very hard PA at the highest intensity level (Ainsworth et al., 2015).

Generally speaking, PA logs are thought to minimize errors associated with long-term recall of activity and estimation of activity frequency; however, PA logs are burdensome for participants to complete and specify the activities to be measured *a priori*, thus having the potential to create systematic errors (Ferrari, Friedenreich, & Matthews, 2007). Both PA records and logs are limited by response rates, the degree to which participants follow instructions, and the potential bias of an instrument toward any given activity (Ainsworth et al., 2015; Troiano & Dodd, 2008). In respect to the latter limitation, instrument-specific bias toward a given activity or activity type can be difficult to predict due to the random nature of errors associated with an instrument (Ainsworth et al., 2015).

Physical activity recalls and questionnaires. PA questionnaires are specialized questionnaires designed to assess an individual's PA behaviors. These questionnaires can take a variety of forms and may include a combination of recall- and questionnaire-based formatting to gather information about PA patterns (Ainsworth, 2010). PA questionnaires typically rely on individual self-reports (although proxy-report questionnaires are less frequently used) to answer a series of questions regarding the frequency, intensity, duration, type, and context of PA and can vary in detail and length.

PA recalls are often similar to questionnaires but instead of the individual having to answer detailed questions, a trained facilitator typically prompts individuals to recall their PA over a specified time period. Utilizing 24 hour PA recalls removes respondent burden and allows for more detailed data collection (Ainsworth, 2010). Recalls can also take the form of a questionnaire which involves a period of no more than one month of past PA history and requires identification of frequency and duration within a certain specified activity type or category. Although this latter form of data collection (i.e., PA recall in questionnaire form) can be used to measure compliance with PA guidelines or establish dose-response relationships with study outcomes, they are rarely seen in the literature as a PA assessment method due to recorder bias and respondents' inability to average frequencies and duration of PA during the past week or month (Ainsworth et al., 2015).

Global PA questionnaires are typically shorter in length (1-4 items) and aim to provide a general classification of PA status (e.g. active vs. inactive). Global PA questionnaires may also provide some insight into activity type and general classifications regarding the activity setting or domain (Ainsworth, 2010). For a more comprehensive look into the frequencies and durations of multiple types of PA over a prolonged period of time, longer PA questionnaires are available with 30 or more items covering time frames of 1 year to a lifetime. Undoubtedly, PA questionnaires are the most commonly used instrument to assess PA behaviors in large-scale epidemiological studies (Nguyen & El-Serag, 2010). Specific to the focus of this thesis, PA questionnaires are the primary assessment method used for ascertaining population estimates of compliance to national guidelines for PA (Ainsworth et al., 2012; Physical Activity Guidelines Advisory Committee, 2008).

Historically speaking, questionnaires represent the primary choice of PA assessment for deployments in large-scale applications (i.e., large prospective cohort epidemiological investigations) and continue to see widespread use today due to their low cost, ease-of-distribution, high versatility, and low participant burden (Helmerhorst et al., 2012). On the other hand, PA questionnaires continue to be difficult to utilize as a comparable measure between research studies due to the wide array of questionnaires used within the literature and the lack of congruency in scoring protocols which may vary depending on demographics of the sample population (Ainsworth et al., 2012). Since their introduction, outputs from objective PA assessment methods have been readily compared to those obtained via PA questionnaires and repeated analyses show discrepancies between these two methods which implies a need for caution when interpreting such comparative data (Ainsworth et al., 2015; Atienza et al., 2011; Ham & Ainsworth, 2010; Prince et al., 2008; Schuna et al., 2013; Troiano et al., 2008; Tucker et al., 2011).

Objective physical activity assessment methods.

Laboratory methods.

Direct and indirect calorimetry. There are two primary methods used to estimate the heat effect, and hence energy expenditure, associated with PA in humans. The first method, direct calorimetry, measures the heat produced by an individual while enclosed in a specialized chamber (i.e., direct calorimeter), where the amount of heat produced is a function of metabolic rate. Direct calorimetry provides highly accurate estimates of energy expenditure with relative error rates below 1 percent (Ainsworth, 2010). In combination with contextual data regarding any activity that may be occurring inside the chamber, energy expenditure estimates can be used to calculate the absolute intensity (i.e., METs) of PA. However, this method requires that individuals be confined in specially designed chambers that are small, expensive, and impractical for the study of usual daily PAs or for use with large samples (Laporte, Montoye, & Caspersen, 1985; Montoye et al., 1982).

The second method which can be used to estimate the heat effect associated with human bodily movement is indirect calorimetry. This method relies on measurements of oxygen (O_2) consumption and carbon dioxide (CO_2) production to estimate energy expenditure as these two respiratory quantities are precisely and directly related to human metabolism. Relatively accurate estimates of energy expenditure can be quickly obtained from O_2 measurements alone (i.e., 1L O_2 consumed = 5 kcals; Ainsworth, 2010); however, the combination of O_2 consumption and CO_2 production provide more precise estimates (i.e., Weir equation: 3.9 * L O2 consumed + 1.1 * L CO2 produced; Weir, 1949). Although easier to implement than direct calorimetry, indirect calorimetry provides estimates of energy expenditure that are only slightly less accurate with typical error rates of approximately 2 to 3 percent (Ainsworth, 2010; Laporte et al., 1985). Similar to direct calorimetry, if resting metabolic rate is known, energy expenditure estimates from indirect calorimetry can be used to calculate absolute intensity (i.e., METs) of PA. Indirect calorimetry data collection has evolved significantly since it was first conceptualized in the early 20th century giving researchers the ability to collect data in real time using whole-room chambers, stationary metabolic carts, or portable metabolic units (Salier Eriksson, Rosdahl,

& Schantz, 2012). However, neither direct nor indirect calorimetry are practical for assessing PA in large samples of individuals when considering the monetary cost and resources necessary to implement these methods. Additionally, indirect calorimetry methods can be impractical for the assessment of free-living PA because they often impede normal PA patterns (Laporte et al., 1985).

Doubly labeled water. The doubly labeled water method is often considered the "Gold Standard" for assessing free-living energy expenditure (Schoeller, 1988; Yang & Hsu, 2010). This method requires participants to ingest engineered water in which hydrogen and oxygen have been replaced with uncommon isotopes of the respective elements (Ainsworth, 2010). After ingestion of the doubly labeled water (i.e., dosing), elimination rates of the uncommon isotopes are tracked via urinalysis at 1 to 2 weeks and used to calculate energy expenditure over the measured time period (Laporte et al., 1985). Although this method is quite accurate, with error estimates ranging from 2 to 10 percent, it is very costly and thus mainly utilized in validation studies rather than large scale epidemiological investigations (Laporte et al., 1985; Yang & Hsu, 2010).

Field methods.

Direct observation. This method entails having a trained individual use a structured system to record levels of PA over a period of time while coding their activity level using a set of established activities that have been correlated with different rates of energy expenditure (Ainsworth, 2010). Direct observation allows for classification of free-living PA behaviors relevant to context and environment, which are major influences on the duration and type of PA ultimately completed (McKenzie, 2002). Direct observation of PA in free-living settings is not commonly practiced among adults and is mainly utilized with young children and adolescents. The lack of direct observation investigations among adults is primarily due to an absence of validation studies examining the relationships between directly observed behavior and criterion measures of energy expenditure (McKenzie, 2002). Additionally, it is generally accepted that adults are able to recall activities more accurately than children. However, there are several studies of direct observation of physician's PA education sessions with adult patients (Anis et al., 2004; Podl, Goodwin, Kikano, & Stange, 1999). Validation of direct observation systems in children have typically been performed while using heart rate monitoring, accelerometry, or indirect calorimetry as the criterion measure of PA (Sirard & Pate, 2012).

A few examples of direct observation systems that utilize similar PA coding schemes (e.g., lying down, sitting, standing, walking, and very active), but in a variety of different settings and populations (e.g., young children at home and during preschool recess, structured physical education classes, and groups in non-structured leisure-time settings), include the Behaviors of Eating and Activity for Children's Health Evaluation System (BEACHES; McKenzie, Sallis, Nader, et al., 1991), System for Observing Fitness Instruction Time (SOFIT; McKenzie, Sallis, & Nader, 1991), and System for Observing Play and Leisure Activity in Youth (SOPLAY; McKenzie, Marshall, Sallis, & Conway, 2000). Some direct observation systems, including the aforementioned BEACHES, also include coding for nutritional behaviors. Additionally, SOFIT includes a coding scheme for assessing teacher behavior, while SOPLAY uniquely looks at the group dynamics associated with PA rather than focusing on individual-level contextual factors (McKenzie, 2002).

Common between-method variations in direct observation systems include utilizing different modes of recording (computer, hand-written, and/or both) and observation intervals (McKenzie, 2002). Although direct observation is a valuable tool for measuring a wide range of PA components (e.g., intensity, duration, type, context, etc.), the method is often cumbersome in practice due to the extensive and continual observer training necessary to ensure validity and interobserver reliability of collected data (McKenzie, 2002; Sirard & Pate, 2012). In general, reactivity to this form of measurement is believed to be minimal (Puhl, Greaves, Hoyt, & Baranowski, 1990).

Global positioning systems. Although the global positioning system (GPS) has served as the world's preeminent geospatial technology over the past 20 years, its introduction for use with PA assessment and monitoring is a more recent development (Krenn, Titze, Oja, Jones, & Ogilvie, 2011). When used in PA assessment applications, GPS devices provide contextual information (i.e., location, neighborhood, speed of locomotion, etc.) and are typically used in conjunction with other PA assessment methods. As an example, GPS has been used in combination with accelerometers to match activity intensity with location and breadth of activity to establish the relationship between PA and our built-environment (Butte, Ekelund, & Westerterp, 2012). GPS has also been used in concurrence with GIS (Geographic Information Systems) which describes the characteristics of the surroundings, as an objective means of investigating the relationship between the natural- and built-environments and location-based PA (Krenn et al., 2011). Data recorded by portable GPS units are sufficiently valid and reliable to track participants' movements and help researchers understand where PA occurs (Benson, Bruce, & Gordon, 2015; Butte et al., 2012; Rodriguez, Brown, & Troped, 2005).

Several limitations of the GPS method include high participant burden, complex data collection, processing, and analysis techniques, and high equipment costs (Butte et al., 2012). The majority of published GPS-related PA research has utilized commercially available units and watches among professional and semi-professional sports teams; however, with the advent of smartphones, researchers may no longer be limited by the high costs of this technology when considering deployment in large-scale population- or community-based applications (Benson et al., 2015). To clarify, GPS and triaxial accelerometers are now embedded in nearly all commercially available smartphones. In combination, these two technologies can be used to assess PA while also assisting to motivate participants who are partaking in PA interventions through shared individualized feedback (Butte et al., 2012). This burgeoning area of research, which combines accelerometry and GPS, affords researchers an opportunity to understand how the environment can impact where individuals are able to obtain PA (Rodriguez et al., 2005; Troped et al., 2008).

Heart rate monitors. Heart rate monitors (HRMs) are one of the most commonly used methods to estimate intensity of PA in both laboratory and free-living settings (Ainsworth et al., 2015; Dale et al., 2002). HRMs are lightweight devices that continually monitor heart rate and which can be used to predict PA energy expenditure based on an assumed linear relationship between heart rate and VO_2 responses to activity (Ainsworth, 2010; Ceesay et al., 1989). HRMs provide a direct indicator of the physiological responses associated with PA; however, due to considerable between-person variation in the heart rate-VO_2 relationship, a correction method is often utilized to refine energy expenditure estimates.

One such valuable and reliable correction method includes the FLEX heart rate, which establishes individual correction curves for heart rate and VO_2 associations (Ainsworth, 2010; Butte et al., 2012; Ceesay et al., 1989). Empirically, FLEX heart rate is defined as the mean of the highest heart rate at rest and the lowest during exercise (Ceesay et al., 1989; Janz, 2002). There are a large variety of commercially-available HRMs to choose from, however, almost all of the continuous HRMs use the electrocardiogram (ECG) signal to detect beat-to-beat heart rate via an ECG transmitter attached to the chest. Most monitors utilize telemetry or an infrared downloading unit to allow heart rate data to be transferred to a computer for analysis. HRMs are an excellent option for measuring physiological responses during activities which are not conducive to monitoring by accelerometers (e.g., swimming, cycling, and other non-ambulatory activities).

Generally speaking, interdevice agreement between HRMs is high; however, the usefulness of HRMs as a PA assessment method can be limited if participants are completing drug regimens that modify heart rate responses (e.g., beta blockers, central nervous system stimulants, thyroid medications, etc.; Dale et al., 2002; Janz, 2002). It is also important to remember that HRMs are most useful for applications concerned with measuring relative rather than absolute intensity of PA. Additional limitations associated with assessing PA using HRMs include, the training state effect of the heart rate and VO_2 relationship, the decreased linear relationship of heart rate and VO_2 and light-intensity PA, and the lack of consensus regarding the optimal method for prediction of energy expenditure using heart rate data (Ainsworth, 2010; Ainsworth et al., 2015; Dale et al., 2002).

Pedometers. Pedometers represent one of the oldest methods used to measure PA (Bassett & Strath, 2002). Simply translated, the pedometer is best defined as a "step counter." The invention of this technology is credited to the famous renaissance polymath Leonardo da Vinci who illustrated the principles behind the mechanical pedometer in the 15^{th} century (Bassett & Strath, 2002). The earliest versions of pedometers were introduced by the American Founding Father Thomas Jefferson who had purchased a "conte-pas" (step counter) in Paris to share with his friends and to record his walking (Ainsworth et al., 2015; Bassett & Strath, 2002). Early forms of pedometers included a hip-worn mechanical sensor to identify steps when sufficient force was generated from a typical heel strike during ambulation. These initial generations of devices were primarily used for surveying rather than for assessing PA in free-living contexts (Ainsworth et al., 2015; Bassett & Strath, 2002).

The first pedometers widely used for assessing PA incorporated electronic methods to record step counts by using a spring-suspended lever arm as part of an electronic circuit. As an individual ambulates, the lever arm moves up and down to open and close an electronic circuit, allowing for an internal counter to digitally capture the number of accumulated steps over a given time interval. These pedometers are still available and used for research purposes to this day; however, the lever arm pedometer has since been succeeded by more accurate devices that incorporate piezoelectric or capacitive accelerometers to measure accumulated steps (Ainsworth et al., 2015; Berlin, Storti, & Brach, 2006). Advanced electronic pedometers (piezoelectric and capacitive devices) are part of a broader family of small electronic devices known as microelectromechanical systems (MEMS) and utilize algorithm-based processing methods of analog or digital signals to identify steps associated with human movement (Ainsworth et al., 2015).

In addition to using pedometers as a PA assessment method, a substantial body of empirical evidence has demonstrated that pedometers can also be an effective PA intervention tool (Bravata et al., 2007). A systematic review conducted by Bravata et al. (2007) concluded that pedometer-based interventions focusing on step-related goals are effective for increasing PA and eliciting clinically relevant reductions in body weight and blood pressure.

As pedometer usage has increased in research and non-research settings, public health interest has grown in developing appropriate recommendations of daily ambulatory behavior necessary to promote health and overall wellbeing (Tudor-Locke & Bassett, 2004; Tudor-Locke et al., 2011). Knowing “how many steps/day are enough?" has been a question of much debate with the consistent recommendation of "10,000 steps/day" becoming a popular mass media and research talking point (Tudor-Locke & Bassett, 2004; Tudor-Locke et al., 2011). This recommendation originated from Japan in the 1960's when a popular pedometer manufacturer (Yamasa Corporation, Tokyo, Japan) nicknamed their product "manpo-kei," which when literally translated stands for "ten-thousand steps meter," (Tudor-Locke, Hatano, Pangrazi, & Kang, 2008). More recently, other steps/day thresholds have been used by researchers to categorize PA at the individual or group levels (Tudor-Locke & Bassett, 2004; Tudor-Locke, Johnson, & Katzmarzyk, 2009). Tudor-Locke and Bassett (2004) previously proposed "zones of steps" to help categorize gradations of step-defined PA for healthy adults: 1) ≤ 5,000 steps/day (sedentary); 2) 5,000–7,499 steps/day (low active); 3) 7,500–9,999 steps/day (somewhat active); 4) ≥10,000–12,499 steps/day (active); and 5) ≥12,500 steps steps/day (highly active). Between the two primary anchors of 5,000 and 10,000 steps/day (sedentary and active, respectively), they reported smoothing the categories to convenient 2,500 steps/day increments. It is important to recognize these steps/day guidelines were intended to be interpreted loosely (Tudor-Locke, Bassett, et al., 2008). There are large steps/day variances between sex, age groups, and health statuses and a clearly established dose-response relationship requires more epidemiological data (Tudor-Locke & Bassett, 2004).

The now ubiquitous "Fitness tracker" pedometers from various companies like Nike, Jawbone, Fitbit, Garmin, and Pivotal Living, among others, have become highly marketable and affordable tools for consumers who want to maintain a healthy lifestyle and track their activity (Ainsworth et al., 2015). The majority of pedometers are designed to be worn on the hip, although the most accurate placement for detecting steps appears to be on the ankle (Karabulut, Crouter, & Bassett, 2005). With this in mind, newer products and other more complex technologies with a multitude of measurable variables (e.g. accelerations, energy expenditure, sleep, water intake, etc.) are typically designed to be worn on the wrist and their accuracy may be limited (Ainsworth et al., 2015).

Pedometers in any form may have decreased accuracy in detecting steps during a variety of activities which are non-ambulatory in nature (Dale et al., 2002). This limitation is primarily attributable to several design considerations as pedometers are manufactured with the primary purpose of measuring walking. As such, pedometers often do not adequately measure PA during seated, upper-extremity, pushing, lifting, and other chore based activities (Berlin et al., 2006). Additionally, most pedometers cannot estimate time spent in different intensities of PA throughout the day (Tudor-Locke & Bassett, 2004). However, newer generations of pedometers which store minute-by-minute step data are beginning to overcome this limitation through the quantification of stepping cadence (steps/minute), which is a proxy indicator of PA intensity (Tudor-Locke & Rowe, 2012). Regardless, pedometers remain appealing in comparison to other forms of objective PA monitoring because the outputted steps/day metric is easily understood and interpreted (Ainsworth et al., 2015), the devices are typically affordable (Berlin et al., 2006), and the method is non-invasive and easy to administer in large groups (Bassett & Strath, 2002; Dale et al., 2002).

Accelerometers. Accelerometry based PA monitors have become widely acknowledged as a useful method to measure and evaluate PA in either free-living or clinical/laboratory settings (Yang & Hsu, 2010). The expansion of accelerometry in the research literature since the early 1980s is evident through a simple publication count indicating that an astounding 600 plus articles per year involving the terms “physical activity” or “exercise” and “accelerometer” or “accelerometry” were published in 2012 and 2013 (Troiano et al., 2014). Accelerometers, as the name implies, measure acceleration of an object in motion along a reference axis. In comparison to other vector quantities such as displacement or velocity, acceleration is the preferable measure for assessing human movement as this quantity is more directly related to the intensity, frequency, and total energy costs of PA (Chen & Bassett, 2005; Yang & Hsu, 2010).

Accelerometers are favorable among researchers monitoring human movement for a multitude of reasons including their high degree of reliability and insensitivity to impact or tilt like actometers or pedometers (Mathie, Coster, Lovell, & Celler, 2004; Meijer, Westerterp, Verhoeven, Koper, & ten Hoor, 1991). However, all accelerometers are not created equal and they can be defined by several different characteristics: 1) requires (or does not require) an external power supply, and 2) responds (or does not respond) to static acceleration (Chen & Bassett, 2005; Mathie et al., 2004). The development of MEMS technology has made accelerometers easier to manufacture in miniature forms, reduced power consumption, and enhanced sensor performance at relatively low cost (Roylance & Angell, 1979; Yang & Hsu, 2010). Three commonly utilized accelerometer technologies include pieziorésistive, piezoelectric, and differential capacitive accelerometers. In terms of measurement characteristics, an accelerometer is typically defined in terms of its sampling frequency (Hz; e.g., 30 to 100 Hz), sensitivity (*g*; e.g., ± 8 g), and number of measurement axes (e.g. uniaxial = 1 axis; biaxial = 2 axes; triaxial = 3 axes).

The first generation of accelerometers used in PA research included the Caltrac, Tritrac-R3D, RT3, CSA, ActiGraph, Actical, and Actiwatch devices (Chen & Bassett, 2005; Dale et al., 2002). This generation or class of accelerometry devices had several advantages including their small size, noninvasiveness, and limited impact in obstructing typical human movement while wearing the device (Chen & Bassett, 2005). Best practices regarding accelerometry implementation, including interpretation of collected data and positioning of wearable activity monitors (i.e., hip- vs. wrist-worn placements), have been discussed and debated in great length among researchers (Freedson et al., 2012; Troiano et al., 2014). Outputs from the accelerometer tend to vary dependent upon where the device is placed relative to the participant, the participant's posture, and the activity being performed (Mathie et al., 2004). In addition, other major contributing factors to variability in accelerometer outputs are the resolution of data collection (known as an "epoch") and the analytical approach applied to the raw data output known as "activity counts."

In regard to the resolution of data collection, there are pros and cons associated with using shorter or longer epochs. In general, shorter epochs (e.g., 15 seconds) are better suited for measuring short-bursts of activity and used quite frequently with accelerometry applications among pediatric populations (Pate, O'Neill, & Mitchell, 2010). However, there are concerns that epochs of such short durations do not adequately represent the energy cost of an activity largely due to the delayed O_2 response as a result of PA (Chen & Bassett, 2005). Conversely, longer epochs (i.e., 60 seconds or more) are perhaps less affected by the aforementioned O_2 delay; however, issues can arise if multiple activity intensities occur within a particular epoch as only the average of those multiple intensities will be reflected (Ayabe, Kumahara, Morimura, & Tanaka, 2013; Chen & Bassett, 2005). It has yet to be determined whether a specific set of cut-points are superior to the rest; however, appropriate cut-points must be chosen based upon the specific accelerometer used, the population being assessed, and the research questions being asked (Rothney, Schaefer, Neumann, Choi, & Chen, 2008).

Calibration studies are typically conducted among a population of interest with the purpose of identifying activity count cut-points that correspond to defined ranges of absolute intensity that are typically characterized as sedentary, light, moderate, or vigorous ($\leq$ 1.5 METs, 1.6-2.9 METs, 3-5.9 METs, and $\geq$ 6 METs, respectively; Kozey, Lyden, Howe, Staudenmayer, & Freedson, 2010; Sedentary Behaviour Research Network, 2012). This method of calibration has produced wide-ranging estimates for activity count cut-points in both adults and children which has become known as the “cut-point conundrum,” (Matthews, 2005). Moreover, the processes used to calculate activity counts are proprietary and vary between device manufacturers (Chen & Bassett, 2005; Troiano et al., 2014). As such, activity count outputs are not comparable between devices from different manufacturers. Although uniaxial and triaxial accelerometers can be utilized quite easily in free-living environments, limitations of the first generation of PA monitoring devices (e.g., predetermined epoch, insufficient on-board data storage, acceleration drift, need for recalibration, etc.) prompted the development of a second generation of multi-sensor systems.

Multi-sensor systems. Multi-sensor systems are measurement technologies that combine multiple mechanical and physiological sensors to aide in providing a more complete and precise measure of PA and energy expenditure (Ainsworth et al., 2015). Measurement technologies incorporated into a multi-sensor system may include, but are not limited to, accelerometry (with multiple placements around the body), galvanic skin response, respiration, skin and core temperature, bioelectrical impedance, GPS, and heart rate. Continued development in the design and manufacture of solid-state electronics has resulted in substantial size reductions in sensor technologies. This now allows for various sensor technologies to be integrated into consumer products like shoes, wrist-worn watches, and mobile phones, while also providing researchers more flexibility in choosing a particular PA assessment technology or device for their specific application (Ainsworth et al., 2015; Altini, Penders, Vullers, & Amft, 2015).

One of the first multi-sensor devices used in PA assessment applications is known as the Intelligent Device for Energy Expenditure and Activity (IDEEA;

MiniSun LLC, Fresno, CA), which includes five fixed accelerometers mounted on the chest, thighs, and feet. Another early multi-sensor device used in PA assessment is the Actiheart (CamNtech Ltd, Cambridge, UK), which combines heart rate and accelerometry data to provide more accurate estimates of energy expenditure than either sensor technology alone (Ainsworth et al., 2015; Yang & Hsu, 2010). The IDEEA is able to quantify and accurately identify most activities in free-living adults; however, a major short coming of this technology is its inability to measure arm movement directly (Zhang, Werner, Sun, Pi-Sunyer, & Boozer, 2003). Newer, smaller, and integrated multi-sensor technologies include the Zephyr Bioharness (Zephyr Technology Corp., Annapolis, MD) which combines triaxial accelerometry, heart rate, and respiration in a chest-worn strap, and the SenseWear Armband (bodymedia, Inc., Pittsburg, PA), which combines triaxial accelerometry, skin temperature, heat flux, and galvanic skin response in a single unit worn on the upper arm (Ainsworth et al., 2015).

To illustrate the benefits of a multi-sensor system, Gao, Bourke, and Nelson (2014) previously tested the concept of utilizing a multi-sensor system for the identification of activity type in comparison to single sensor monitors. The experimental results from the multi-sensor system, when processed using a supervised machine learning technique (i.e., decision tree classifier), indicated a 96.4% recognition accuracy in predicting activity type in comparison to the best single sensor performance of 92.8%.

Current Physical Activity Guidelines

The 2008 PAGA are the most current, up-to-date recommendations for PA distributed by the U.S. federal government. As previously mentioned, this recommendation states that healthy adults should accumulate at least two-and-a-half hours (150 minutes) of weekly moderate-intensity or one hour and fifteen minutes (75 minutes) of vigorous-intensity aerobic PA (in $\geq$ 10-minute bouts) or an equivalent combination of the two (U.S. Department of Health and Human Services, 2008). Although resistance training recommendations are a key component of the 2008 PAGA, our focus herein concerns the specific aerobic guideline. The following sections will discuss how the current guidelines were derived from specific epidemiological research, what preceded the current guidelines, and future directions beyond the 2008 PAGA.

Development of current physical activity guidelines for adults. The process by which the 2008 PAGA were developed has a long and storied past. Although impossible to pick an exact starting date for this process, the first epidemiological evidence linking greater amounts of PA with reduced risks for CVD and CVD-related mortality was presented by Morris, Heady, Raffle, Roberts, and Parks (1953) as part of the London Transport Workers Study. Specifically, Morris and colleagues demonstrated that physically inactive bus drivers had a significantly higher risk for nonfatal and fatal heart attack when compared to the more physically active bus conductors. Although these findings may seem intuitive on face value, no prior investigations had quantitatively demonstrated the protective health benefits of regular PA before this time (Paffenbarger, Blair, & Lee, 2001).

The foundation for today's current PA recommendations were initiated in the middle decades of the 1900s by means of large-scale epidemiological studies designed to investigate underlying causes of CVD, a major public health concern at the time (Liguori & Schuna, 2013). Among these studies include the Framingham Heart Study (Kannel, Feinleib, McNamara, Garrison, & Castelli, 1979), the Harvard Alumni Health Study (Lee & Paffenbarger, 2000), the California Longshoremen Study (Paffenbarger, Gima, Laughlin, & Black, 1971), and The London Transport Workers Study (Morris et al., 1953; Norman, 1958). Collectively, results from the aforementioned studies demonstrated that PA was inversely related to CVD risk in a general dose-response fashion (i.e., greater amounts of PA were associated with further decreases in CVD risks when compared with lower amounts of PA; Williams, 2001). These ground breaking investigations have subsequently been followed by numerous research studies examining the long-term health impacts of PA on a variety of health outcomes (Paffenbarger, Hyde, & Wing, 1987; Williams, 2001; Wilson et al., 1998).

Although the precise dose-response relationship between PA and various health outcomes has been difficult to discern, recent work by Church, Earnest, Skinner, and Blair (2007), as part of the Dose-Response to Exercise in Women (DREW) trial, has somewhat elucidated this relationship. The DREW study was a randomized controlled trial that examined the effects of 50%, 100%, and 150% of the National Institutes of Health (NIH) Consensus Panel (1996) PA recommendation on cardiorespiratory fitness in sedentary, overweight or obese postmenopausal women with elevated blood pressure. The primary outcome of this study was peak absolute oxygen consumption (L/min), while the secondary outcome was peak relative oxygen consumption (ml/kg/min). Results from the study provided objective data that agreed with previous epidemiological findings that greater amounts of PA were associated with additional health benefits, with the primary benefit being realized in the form of improved cardiorespiratory fitness (Church et al., 2007).

In an effort to improve our understanding of the health effects associated with regular PA, additional research has examined inter-individual variations in responsiveness to regular PA or exercise training based upon various genotypic and phenotypic characteristics (Bouchard et al., 1999; Bouchard & Rankinen, 2001). This research has helped demonstrate that there is considerable heterogeneity in the responsiveness of various cardiometabolic risk factors to regular PA. Additionally, this line of research has demonstrated that age, sex, and ethnic origin are not major determinants of the biological adaptations associated with regular PA.

Although a substantial amount of empirical research evidence supports the importance of both cardiorespiratory fitness and regular PA (which are not one in the same) in providing substantive long-term health benefits, there has been considerable debate over whether cardiorespiratory fitness or PA is the more important determinant (Blair, Cheng, & Holder, 2001; Williams, 2001). Cardiorespiratory fitness and PA are closely related in that higher levels of fitness are associated with greater capacities to perform a variety of PAs, while higher levels of PA are likely to promote improvements in fitness over time (Blair et al., 2001). Despite the academic debate regarding the relative importance of cardiorespiratory fitness and PA, increasing daily levels of PA and overall cardiorespiratory fitness should both be public health priorities (Talbot, Morrell, Metter, & Fleg, 2002). Not only has a physically active lifestyle been shown to aid in chronic disease prevention and improve independent mobility throughout adulthood (Chodzko-Zajko, Schwingel, & Park, 2008), it also provides benefits to individuals with existing chronic disease or previously sedentary lifestyles (Brosseau et al., 2004; Steffen-Batey et al., 2000).

1995 CDC/ACSM recommendation. In 1995 the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) issued a public health recommendation that ‘‘every U.S. adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week,” (Pate et al., 1995; Pollock, Feigenbaum, & Brechue, 1995). The purpose of this recommendation was to provide a ‘‘clear, concise, public health message,’’ that would “encourage increased participation in PA,” by a largely sedentary U.S. population (Pate et al., 1995). The foundation for these recommendations were based on the ACSM’s *Guidelines for Exercise Testing and Prescription* and the revised Exercise Standards of the American Heart Association (AHA; Pollock et al., 1995). Although pivotal in the progression of increased awareness of PA as a means to decrease the risk of chronic disease, more research was needed to help bolster the recommendation and provide a clearer message regarding the dose-response relationships associated with regular PA.

1996 Surgeon General's Report on Physical Activity and Health. A turning point occurred within the field of PA and public health when the first ever Surgeon General's Report on PA and Health was released by the CDC in 1996 (U.S. Department of Health and Human Services, 1996). Preparation for this report started in 1994 when the Office of the Surgeon General authorized the CDC to serve as the lead agency in preparing this report in partnership with the President's Council of Physical Fitness and Sports. Numerous additional representatives from other prominent institutions within the field also consulted on the formulation of the final report (i.e., the NIH and other non-federal organizations including the American Alliance for Health, Physical Education, Recreation, and Dance, the ACSM, and the AHA; U.S. Department of Health and Human Services, 1996).

Within the report, the PA recommendation emphasized that individuals of all ages should participate in a minimum of 30 minutes of moderate-intensity PA (MPA; such as brisk walking) on most, if not all, days of the week (i.e., the same recommendation as detailed in the 1995 CDC/ACSM joint statement; U.S. Department of Health and Human Services, 1996). The report also recognized that greater health benefits could be obtained by engaging in PA of more vigorous-intensities or for longer durations. Additionally, the report acknowledged that cardiorespiratory endurance activity should be supplemented with strength-developing exercises at least twice per week for adults. The goal of such strength-development exercise is to improve musculoskeletal health, reduce the risk of falls, and to improve or maintain the ability to engage in activities of daily living throughout adulthood.

The primary public health message of this report was that Americans can substantially improve their health and quality of life by including moderate amounts of PA in their daily lives (U.S. Department of Health and Human Services, 1996). This recommendation was practical and encouraged individuals who may dislike vigorous-intensity PA (VPA) to begin engaging in MPA. Additionally, the recommendation encouraged individuals who were already engaging in MPA to increase activity levels as a means to receive further health benefits. The report also emphasized the need to increase PA efficacy in the general public and to create more opportunities for PA by encouraging professionals from different disciplines (e.g. behavioral and social scientists, exercise specialists, recreation specialists, health professionals, architects, city planners, and engineers) to work together in an effort to provoke greater long-lasting change at the community, state, and national levels.

2007 ACSM/AHA recommendation. For over 10 years, the PA recommendations set forth in the 1996 Surgeon's General Report on PA and Health remained unchanged. These PA Recommendations were finally updated in 2007 as part of an effort to encourage public health messaging that was more inclusive of PA promotion as previous messaging techniques proved to be less effective than initially anticipated (Haskell et al., 2007). Alarming data trends from the CDC's BRFSS indicated that although leisure-time PA remained fairly constant since 1996, approximately 23.7% of adults were still not participating in any leisure time PA (Haskell et al., 2007; Liguori & Schuna, 2013).

The 2007 ACSM/AHA recommendation included an updated review of the evidence regarding PA and health, which involved a consensus panel of experts composed of physicians, epidemiologists, and public health specialists (Haskell et al., 2007; Liguori & Schuna, 2013). The updated recommendation was similar with previous recommendations in that it called for 30 minutes of daily aerobic MPA; however, rather than stating that this PA should be accumulated on "most, preferably all, days per week" it was further clarified that this intensity and duration of PA should be accumulated on at least five days per week (Haskell et al., 2007). In terms of the tangible benefit associated with this wording change, the revised language proved instrumental in allowing the CDC to track the percentage of adults who met the PA guidelines in a more objective fashion (Physical Activity Guidelines Advisory Committee, 2008). Furthermore, the updated recommendations offered the alternative option of participating in VPA for a minimum of 20 minutes three days a week. Although this was previously implied, it was further clarified that this level of aerobic activity, and less demanding MPA, could be obtained in separate bouts throughout the day as long as they were 10 minutes or more in duration (Haskell et al., 2007). The recommendation also emphasized that even greater health benefits could be obtained by performing PA beyond the minimum requirement; however, an upper limit was not established and could vary person-to-person.

2008 Physical Activity Guidelines for Americans. Shortly after the publication of the 2007 ACSM/AHA updated PA recommendations, the U.S. federal government released their first comprehensive guidelines for PA in 2008 (U.S. Department of Health and Human Services, 2008). The 2008 PAGA represents the most current PA recommendations that are utilized today by health professionals and policy makers to help guide the public towards improved health. Significantly, the 2008 PAGA detailed specific prescriptions regarding the amounts and types of PA which should be completed by children and adolescents (6 to 17 years), adults (18 to 64 years), and older adults (65+ years). This new lifespan approach emphasized that activity should be encouraged throughout the life cycle if one wants to receive maximal health benefits. In addition, the 2008 PAGA offered suggestions to aide health professionals in promoting PA among their clients and patients.

As previously mentioned, the 2008 PAGA (U.S. Department of Health and Human Services, 2008) states that:

> For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. (p. 22)

A major difference in this recommendation compared to the updated 2007 ACSM/AHA recommendation includes the removal of a weekly frequency for aerobic activity (e.g. $\geq 5\ d\cdot wk^{-1}$) while instead simply specifying a total weekly duration (Haskell et al., 2007; U.S. Department of Health and Human Services, 2008). This distinction allows for more flexibility and suggests that PA be spread throughout the week rather than accumulated in one single bout. In remaining consistent with previous PA guidelines, the 2008 PAGA specifies that MPA and VPA should be accumulated in bouts of at least 10 minutes in duration.

Assessing Compliance to 2008 Physical Activity Guidelines for Americans

Assessments of compliance to PA guidelines have primarily been conducted by means of subjective self-reports or questionnaire data (Haskell, 2012). However, recently the use of objective PA monitoring to assess compliance to such guidelines has increased (Haskell, 2012; Troiano et al., 2008; Tucker et al., 2011). To assess compliance to U.S. PA guidelines on a population level, several large scale surveillance systems have adopted various PA assessments within their testing protocols (i.e., National Health Interview Survey [NHIS], NHANES, and BRFSS; Carlson, Densmore, Fulton, Yore, & Kohl, 2009).

In brief, these methods of PA data collection have several similarities and differences which will not be discussed at length here. Generally speaking, assessing compliance to PA guidelines using subjective self-report methods typically relies on data from questions that are intended to identify the frequency and duration of participation in activities that are of at least moderate-intensity (Schuna et al., 2013). These subjective self-report methods represent the most common means of assessment used to gauge compliance to PA guidelines in the aforementioned NHIS, NHANES, and BRFSS surveillance systems. However, NHANES has a particular advantage over NHIS and BRFSS, as NHANES has also utilized objective measures (i.e., accelerometer-determined PA) to assess compliance to PA guidelines. Detailed methods regarding the NHIS and BRFSS surveillance systems can be found elsewhere (Centers for Disease Control and Prevention, 2011; National Center for Health Statistics, 2016), while the detailed methods for NHANES are reviewed in the study methods to follow.

It is important to note that two months after the release of the 2008 PAGA, CDC researchers analyzed questionnaire data from the 2007 BRFSS to investigate the percent of individuals that reported meeting the Healthy People 2010 (HP2010) objectives (Centers for Disease Control and Prevention, 2008). This was an attempt to establish baseline comparative data for the 2008 PAGA even though the new recommendations for aerobic PA were different than those used in HP2010 objectives, which called for adults to engage in at least 30 minutes of MPA, 5 days per week, or 20 minutes of VPA, 3 days per week. Although respondents answered questions tailored for assessing compliance to the previous PA recommendations, researchers were able to calculate compliance estimates relative to the 2008 PAGA with these data as well. Results indicated that 64.5% of U.S. adults reportedly met the minimum level of aerobic PA required by the 2008 PAGA based on 2007 BRFSS data. This baseline data analysis is subject to several limitations including self-report bias and exclusion of individuals based on survey parameters (i.e., the survey only targeted respondents with a landline telephone). Nonetheless, this baseline assessment of compliance to the 2008

PAGA suggested that nearly two-thirds of the U.S. adult population was not meeting the recommendation.

Although the majority of published data assessing compliance to PA guidelines entailed the use of subjective self-report measures, the proliferation of objective monitoring technologies has prompted interest in assessing compliance to PA guidelines using these novel methods. Pedometers, although useful for counting steps, are not as useful for estimating time spent in different intensities of PA (e.g., MVPA), a necessary metric for assessing compliance to PA guidelines (Tudor-Locke et al., 2011). In contrast, accelerometers are capable of providing estimates of time spent in different intensities of PA and at face value represent a standardized and objective method for assessing compliance to PA guidelines. Simply put, accelerometers are a researcher valued tool that are able to provide concise, unbiased information regarding time spent in different intensities of PA and that can easily be applied to applications concerned with assessing compliance to current PA guidelines (Troiano et al., 2014).

Discrepancies in compliance estimates. Inconsistencies among statistically derived estimates of compliance to PA guidelines are not uncommon. The inherent methodological differences between subjective and objective forms of PA data collection play a large role in these discrepancies. This presents public health professionals with a significant dilemma as a key indicator of long term health status is compliance to PA guidelines (Physical Activity Guidelines Advisory Committee, 2008; U.S. Department of Health and Human Services, 2008). As such, accurate measurement of PA levels among large populations is a primary objective necessary for understanding the true state of the public health landscape.

Carlson et al. (2009) previously demonstrated the potential for discrepant compliance estimates to PA guidelines using data from the NHIS, NHANES, and BRFSS surveillance systems. Results from a comparative analysis of the NHIS 2005, NHANES 2005-2006 and BRFSS 2005 with the HP2010 PA objectives indicated that 30.2%, 33.5%, and 48.3% of individuals were physically active (i.e., meeting HP2010 PA guidelines), respectively. It is hard to ignore the absolute magnitude of the differences in compliance estimates between the three surveillance systems depicted above. This leaves researchers to question which method is painting the most accurate picture of compliance and what is the actual baseline to build from? Self-report PA measures suffer from a number of major methodological issues including, but not limited to, challenges associated with estimating the frequency and duration of PA (Troiano et al., 2008). It is also important to note that many PA questionnaires are not inherently designed to directly measure compliance to specific PA guidelines, despite the common usage of such questionnaires for this expressed purpose.

In addition to differences between similar types of subjective assessment methods, an even larger issue is the incongruity of subjective and objective measurements of compliance to PA guidelines. It is difficult for subjective and objective measurements to align completely when measuring PA due to the dynamic nature of PA. This is evident by such starkly different values in compliance estimates to PA guidelines, with objective measurements demonstrating that fewer than 10% of U.S. adults are currently meeting the 2008 PAGA (Troiano et al., 2008; Tucker et al., 2011), while subjective measurement methods have indicated that 52% of U.S. adults are compliant with the 2008 PAGA (Centers for Disease Control and Prevention, 2013). This discrepancy in compliance estimates is by no means small (> 40% difference) and is directly related to the large differences in absolute PA estimates (i.e., minutes/week of MVPA) obtained from self-report and objective assessment methods (Schuna et al., 2013; Troiano et al., 2008; Tucker et al., 2011).

Yet another important point for researchers to consider when quantifying levels of PA while assessing compliance to the 2008 PAGA relates to the "equivalent combination" verbiage outlined within the aerobic guideline (U.S. Department of Health and Human Services, 2008). Put simply, this qualification highlights the relevance of PA intensity when assessing compliance to the 2008 PAGA as VPA provides greater health benefits per given unit of time than does MPA (Physical Activity Guidelines Advisory Committee, 2008). To account for this, it has been suggested that every 1 minute of VPA should be considered equivalent to 2 minutes of MPA. When assessing compliance to the 2008 PAGA, one would separately calculate the number of weekly MPA and VPA minutes, multiply the VPA minutes by two, and then sum the resulting product with MPA (i.e., MPA + VPA*2 = MV2PA; U.S. Department of Health and Human Services, 2008). This final quantity (MV2PA) is then compared against the aerobic MPA guideline calling for ≥ 150 minutes/week of MPA. Although used sparingly within the empirical literature base (Tucker et al., 2011), this method of PA quantification most closely follows guidance outlined with the 2008 PAGA. However, compliance to the 2008 PAGA does not appear to be dramatically affected when calculating the equivalent combination of weekly MPA and VPA (i.e., MV2PA) as opposed to simply quantifying weekly MVPA (self-report PA: 2.4 % higher compliance using equivalent combination calculation; accelerometer-determined PA: 1.4% higher compliance using equivalent combination calculation; Tucker et al., 2011).

The aforementioned discrepancies have lead researchers to question the entire process by which we analyze and portray accurate pictures of compliance to PA guidelines. However, it must be remembered that the method that is believed to paint the most accurate picture of PA (accelerometry) is different than the method that was used to derive the 2008 PAGA and all of the recommendations which preceded it (i.e., epidemiological survey data obtained via self-report). This is not to say that our current PA guidelines are without merit or that compliance to these guidelines does not confer substantial health benefits (Physical Activity Guidelines Advisory Committee, 2008). However, this dilemma raises the question as to why have we not tried to investigate a means to align our standard of PA (i.e., weekly minutes of self-reported MV2PA) with the method of measurement many researchers feel is the most applicable means to assess compliance (i.e., accelerometry; Troiano et al., 2014). This clear research gap has prompted us to conduct further analyses that combine data from the 2003-2006 NHANES PAM and PAQ components to identify appropriate accelerometer-determined MV2PA thresholds that correspond to self-reported compliance to the 2008 PAGA (≥ 150 minutes/week of self-reported MV2PA).

Chapter 3. Methods

Data Source

To evaluate the aims of this study, we made use of freely available secondary data from the 2003-2006 NHANES. A determination from the Oregon State University Institutional Review Board (IRB) was sought to determine whether or not this study required IRB review. Because this study utilized non-sensitive and de-identified secondary data, the IRB determined that this study did not meet the definition of human subjects research, and as such IRB review was not required (Appendix A).

National Health and Nutrition Examination Survey 2003-2006

Since 1999, NHANES has been implemented continuously and has served as the primary source of objective health data in the U.S. (Carlson et al., 2009; Tudor-Locke et al., 2009). The survey operates in two-year assessment cycles, which contain approximately 10,000 individuals. NHANES is conducted year-round while using standardized data collection procedures to limit the potential for bias and error. Individuals are recruited to participate in NHANES from pre-identified households that meet specific inclusion criteria. Identified households are visited by a trained interviewer that administers a series of detailed questionnaires. Following completion of the household interview, participants are invited to complete a comprehensive health examination at a mobile examination center (MEC). Similar to other large-scale surveillance systems (e.g., BRFSS), NHANES participants are selected using a complex, multistage probability design to allow for the generation of estimates on various health parameters which are representative of the noninstitutionalized U.S. civilian population (Tudor-Locke et al., 2009). The National Center for Health Statistics Ethics Review Board approved the original survey protocols, and informed consent was obtained for all NHANES participants. A detailed accounting of all NHANES components, study protocols, and procedures can be found at http://www.cdc.gov/nchs/nhanes.htm.

Physical Activity Questionnaire

The subjective manner in which information was gathered about PA behaviors included a household interview component, which was identical in the 2003-2004 and 2005-2006 NHANES cycles (Appendix C). The PAQ was administered by a trained technician and several questions were used to evaluate each participant's involvement in PA during the past 30 days related to transportation, household/domestic tasks, and leisure-time activities. Based upon previously quantified relationships between PA and energy expenditure (Ainsworth et al., 2011; Ainsworth et al., 1993; Ainsworth et al., 2000), transportation related PA, as well as household/domestic tasks, were presumed to be of at least moderate-intensity (Schuna et al., 2013; Tucker et al., 2011a). These types of PA were assessed with two specific questions: 1) "Over the past 30 days, have you walked or bicycled as part of getting to and from work, or school, or to do errands?" and 2) "Over the past 30 days, did you do any tasks in or around your home or yard for at least 10 minutes that required moderate or greater physical effort?" If individuals reported "Yes" to either question they were asked to provide additional information about the frequency and duration of these activities. Participants were also asked to characterize their leisure-time MPA and

VPA with two additional questions: 1) "Over the past 30 days, did you do moderate activities for at least 10 minutes that cause only light sweating or a slight to moderate increase in breathing or heart rate?" and 2) "Over the past 30 days, did you do any vigorous activities for at least 10 minutes that caused heavy sweating, or large increases in breathing or heart rate?" Those who responded "Yes" to either question were asked to specify the activities associated with each intensity and the usual duration and frequency of these activities.

Examination and Laboratory Procedures

Relevant data from the MEC portion of the 2003-2006 NHANES that concerned this investigation included PA data from the PAM sub-component and various anthropometric and cardiometabolic measures obtained during the physician's exam.

Physical activity monitor sub-component. The PAM sub-component incorporating accelerometry was introduced to NHANES in 2003 as a means to objectively assess each participant's PA patterns. This main public health objective was carried out by a trained health or medical technician and began with them initializing specialized PA accelerometers in the MEC. Near completion of the MEC exam, a study staff member asked ambulatory participants (i.e., able to walk on their own power without aid from a medical device or cane) to wear the accelerometer for 7 days during normal waking hours. Participants were informed that the accelerometer was not waterproof and must be removed prior to swimming or bathing. Study staff then directed participants on how to mount the device on the right hip using an adjustable elastic belt that could be easily removed. To be eligible for this portion of NHANES, participants had to be 6 years of age or older. The entire process, from start to finish, including accelerometer initialization, fitting the belt to each participant, and instructing each participant on the proper wearing procedures, was expected to take no more than three minutes total. The PA accelerometer used for this process was the ActiGraph model 7164 (formerly MTI/CSA; ActiGraph LLC, Pensacola, FL, U.S.). After 7 days of wearing the accelerometer, participants returned the device by mail in a postage-paid envelope and were compensated with $40 (Troiano et al., 2008).

Collected PAM data from the 2003-2004 and 2005-2006 cycles are publicly available; however, differences among the cycles of data collection include the fact that the 2005-2006 NHANES included accelerometer-determined step data in addition to activity counts/minute data (Schuna et al., 2013). This made the 2005-2006 NHANES PAM data a more comprehensive data source of objectively measured PA than the previous 2003-2004 NHANES PAM dataset. In December 2007 and June 2008, the raw data files from the 2003-2004 and 2005-2006 cycles were publicly released, respectively. Each data file consisted of multiple records of minute-by minute activity count and step data (2005-2006 only) for each participant. NHANES staff applied indicator variables to these data files to help inform researchers of each accelerometer's calibration status upon return (calibrated vs. not calibrated) and the reliability of each participant's accelerometer data (reliable vs. unreliable; Schuna et al., 2013; Troiano et al., 2008; Tudor-Locke et al., 2009). Examples of data flagged as unreliable were records containing > 10 minutes with 1) 32,767 activity counts/minute (maximum saturation value for the ActiGraph 7164), 2) 0 steps and > 250 activity counts/minute, or 3) > 200 steps/minute. NHANES data processing and treatment included review for outliers and unreasonable values based on published literature and expert judgment.

Physician's physical examination. This component was extensive and different portions were appropriately carried out by either a licensed physician (MD) or medical assistant. Although different aspects of health were examined including vision, hearing, balance, vestibular acuity, body composition, anthropometry, cardiorespiratory fitness, dermatological wellbeing, lower extremity diseases, oral health, and blood pressure (screened for hypertension), we were only concerned with a selection of biomarkers associated with preventable chronic disease. Specifically, we examined important anthropometric and cardiometabolic biomarkers associated with chronic diseases, including BMI, blood glucose levels, total cholesterol, high density lipoproteins, triglycerides and blood pressure (presence of hypertension).

Data Processing and Aggregation

All analyzed data for this investigation were downloaded from the publicly accessible NHANES website (http://www.cdc.gov/nchs/nhanes.htm). To begin the necessary data processing and aggregation for this study, we downloaded transport files (.xpt) provided by NHANES for the 2003-2004 and 2005-2006 cycles, and converted them to comma delimited files (.csv) to allow for cross-program compatibility with spreadsheet management (i.e., Excel) and statistical analysis software (i.e., R). As this investigation was concerned with making generalizations to the U.S. adult population, we retained data from only those participants aged 18-64 years.

Self-report responses to the transportation, household/domestic tasks, and leisure-time PA questions were translated to minutes/week of self-reported MVPA and an equivalent combination of MPA and VPA where additional weight is given to every minute of VPA (MV2PA = MPA + VPA*2). To establish self-reported compliance to the 2008 PAGA, each participant's combined weekly duration of self-reported MV2PA from transportation, household/domestic tasks, and leisure-time PA was dichotomized into one of two categories (U.S. Department of Health and Human Services, 2008). Those participants who achieved ≥ 150 minutes/week of self-reported MV2PA were deemed compliant to the 2008 PAGA while participants achieving < 150 minutes/week were deemed non-compliant.

Minute-by-minute accelerometer data were initially screened to identify periods of non-wear and wear time using publicly available SAS code developed by the National Cancer Institute (http://epi.grants.cancer.gov/nhanes_pam/) which we adapted for implementation in the R statistical programming language. Non-wear time was identified as any interval of at least 60 consecutive minutes of 0 activity counts, with allowance for up to 2 consecutive minutes of activity counts between 0 and 100 (Troiano et al., 2008). Daily wear time was calculated by subtracting non-wear time from the daily total of 1,440 minutes. We retained only those days with 10 or more hours of wear time (≥ 600 minutes/day). Moreover, only those participants that accumulated 4 or more valid days (≥ 600 minutes/day) were included in final analyses (Troiano et al., 2008).

After restricting the wear-marked minute-by-minute accelerometer data to only those observations during the wearing interval, we applied the cut-points proposed by Troiano et al. (2008; MPA: ≥ 2,020 activity counts/minute; VPA: ≥ 5,999 activity counts/minute) to identify minutes of MVPA and MV2PA. We then identified modified bouts of MVPA using an automated algorithm that detected instances of 10 or more consecutive minutes at or above 2,020 activity counts/minute, while allowing for brief interruptions of 1 to 2 minutes below this threshold. Modified 10-minute bouts of MV2PA used the previously identified MVPA bouts with additional weighting for VPA (VPA*2) given to each minute at or above 5,999 activity counts/minute. For each participant, we then summed all daily minutes of accelerometer-determined MVPA and MV2PA occurring in 10-minute bouts, and in total (i.e., no bout requirement), for each day of observation. Average daily accelerometer-determined MVPA and MV2PA were calculated by averaging daily estimates of MVPA and MV2PA across all valid days of observation (≥ 600 minutes/day of wear time). To calculate the aforementioned variables, we utilized a modified version of NCI provided SAS code for implementation in the R statistical programming language.

Statistical Analyses

All statistical analyses were conducted using R (version 3.2.2; R Foundation for Statistical Computing, Vienna, Austria). Due to the complex, multistage stage sampling design employed in NHANES, statistical procedures for sample survey data were used to produce estimates generalizable to the noninstitutionalized U.S. civilian population when appropriate. The level of significance α was set to 0.05.

Descriptive statistics (e.g., means, standard errors, ranges, etc.) were calculated to characterize the analyzed sample in total and following stratification by sex. Variable distributions were explored using graphical techniques (e.g., Q-Q plots, histograms). Between-sex comparisons of descriptive characteristics were performed using *t*-tests (independent samples) for continuous variables and χ^2 tests for categorical variables.

Aim and hypothesis #1. To address aim #1, we conducted analyses in a two-step process. We initially attempted to perform analyses regressing: 1) self-reported MV2PA on accelerometer-determined MV2PA, and 2) accelerometer-determined MV2PA on self-reported MV2PA using linear and poisson regression techniques. After close inspection of potential outcome variables (i.e., self-reported and accelerometer-determined MV2PA), it was decided that neither of these regression-based techniques would be tenable. In brief, the distributions of self-reported and accelerometer-determined MV2PA (in total and in 10-minute bouts) were zero-inflated and right-skewed. Because of this, the linear and poisson regression techniques would not be able to meet requisite assumptions (i.e., independently and identically distributed residuals, homogeneity of variance) should the methods have been employed.

We then fit receiver operating characteristic (ROC) curves to evaluate the performance of accelerometer-determined MV2PA (continuous measure) in predicting self-reported compliance to the 2008 PAGA (binary response: Yes vs. No). ROC curves were fit for the total sample and separately for each sex. Area under the curve (AUC) was quantified for each ROC analysis to assess the ability of accelerometer-determined MV2PA to discriminate between non-compliance and compliance to the 2008 PAGA. An iterative procedure was then used to assess the sensitivity (true positive rate) and specificity (true negative rate) of classification (non-compliance vs. compliance) along all observed values of accelerometer-determined MV2PA. Optimal thresholds of accelerometer-determined MV2PA were then determined using the minimum d criteria (where $d = \sqrt{[(1 - \text{Sensitivity})^2 + (1 - \text{Specficity})^2]}$). Variance estimation for AUC and optimal thresholds were performed using the (n – 1) bootstrap (Rao, Verret, & Hidiroglou, 2013). Confidence intervals (95%) around the ROC curve-defined optimal thresholds for weekly accelerometer-determined MV2PA were then created and compared against the minimum threshold of 150 minutes/week.

Aim and hypothesis #2. To address aim #2, we quantified the sensitivity and specificity of the previously identified accelerometer-determined MV2PA thresholds in predicting self-reported compliance to the 2008 PAGA. Obtained sensitivity and specificity values associated with each threshold were then compared against the *a priori* defined criteria of 80%. Specifically, sensitivity and specificity values were characterized as “acceptable” if they were ≥ 80%.

We then examined the construct validity of the identified accelerometer-determined MV2PA thresholds, in comparison to self-reported MV2PA, by creating dichotomizations representing compliance to the 2008 PAGA (compliant vs. non-compliant) based upon: 1) self-reported levels of MV2PA (≥ 150 minutes/week), 2) accelerometer-determined MV2PA in modified 10-minute bouts (using the previously identified threshold predicting self-reported compliance to the 2008 PAGA), and 3) total accelerometer-determined MV2PA (no bout requirement; using the previously identified threshold predicting self-reported compliance to the 2008 PAGA). A series of multivariable linear regressions were then fitted by regressing a variety of anthropometric (i.e., waist circumference, BMI) and cardiometabolic parameters (i.e., glycated hemoglobin, fasting plasma glucose, triglycerides, low-density lipoprotein, high-density lipoprotein, systolic blood pressure, and diastolic blood pressure) on the aforementioned compliance dichotomizations while controlling for age, sex, education level, smoking status, and employment status. The significance of unstandardized coefficients from the linear regressions was evaluated to determine the associations between each marker of compliance and each dependent variable. We also fit a series of multivariable logistic regression models by regressing a series of binary chronic disease states (i.e., hypertension, hyperlipidemia, obesity, impaired fasting glucose, and diabetes mellitus) on the aforementioned compliance dichotomizations while again controlling for age, sex, education level, smoking status, and employment status. The significance of odds ratios from the logistic regressions was evaluated to determine the associations between each marker of compliance and each chronic disease state.

Aim and hypothesis #3. To address aim #3, we conducted sensitivity analyses to evaluate the effect of different accelerometer-determined MPA and

VPA cut-points (i.e., activity counts/minute) on threshold estimates corresponding to self-reported compliance to the 2008 PAGA. A set of eleven different MVPA cut-points which have been proposed from various calibration studies with adult samples was used to recreate MV2PA (10-minute bouts and in total) estimates for each participant (Table 1; Brage, Wedderkopp, Franks, Andersen, & Froberg, 2003; Freedson, Melanson, & Sirard, 1998; Hendelman, Miller, Baggett, Debold, & Freedson, 2000; Leenders, Nelson, & Sherman, 2003; Nichols, Morgan, Chabot, Sallis, & Calfas, 2000; Swartz et al., 2000; Troiano et al., 2008; Yngve, Nilsson, Sjostrom, & Ekelund, 2003). We then repeated the ROC curve analyses

Table 1

Activity Counts/Minute Cut-Points for the ActiGraph Model 7164 Accelerometer From a Series of Adult Calibration Studies

Authors	MPA activity counts/minute cut-point	VPA activity counts/minute cut-point
Troiano (Troiano et al., 2008)	1,952	5,725
Freedson (Freedson et al., 1998)	2,020	5,999
Brage (Brage et al., 2003)	1,810	5,850
Yngve1 (Yngve et al., 2003)	2,743	6,403
Yngve2 (Yngve et al., 2003)	2,260	5,896
Leenders (Leenders et al., 2003)	1,267	6,252
Hendelman1 (Hendelman et al., 2000)	191	7,526
Hendelman2 (Hendelman et al., 2000)	2,191	6,893
Swartz (Swartz et al., 2000)	574	4,945
Nichols1 (Nichols et al., 2000)	3,207	6,885
Nichols2 (Nichols et al., 2000)	3,285	5,677

Note. Activity counts/minute values that are ≥ the MPA cut-point and < the VPA cut-point are considered MPA. Activity counts/minute values that are ≥ the VPA cut-point are considered VPA. MPA = moderate-intensity physical activity; VPA = vigorous-intensity physical activity.

described above with each of the eleven newly created MV2PA estimates to identify optimal thresholds of accelerometer-determined MV2PA corresponding to self-reported compliance with the 2008 PAGA. All pairwise differences between the newly quantified optimal thresholds (for those thresholds associated with an AUC > 0.6) were then evaluated non-parametrically using the (n-1) bootstrap. Because of the large number of comparisons involved with the sensitivity analyses, we employed a correction to the level of significance α and declared differences significant only when $p < 0.001$.

Chapter 4. Results

In total, 4,784 adults from the 2003-2006 NHANES completed the self-report PAQ and provided ≥ 4 valid days of accelerometer data. Anthropometric and demographic characteristics of the sample (nationally representative of the non-institutionalized adult population aged 18-64 years) are presented in Table 2. Among the analytic sample, no significant difference in mean age between men and women was noted. Likewise, the distribution of participants across age ranges (18-29, 30-39, 40-49, and 50-64 years) was not significantly different between sexes. Men were significantly taller and had a higher body weight on average than women (both $p < 0.001$); however, no significant between-sex difference in BMI was noted. Moreover, no significant difference in the distributions of men and women across race/ethnicity categories were observed.

Mean values of self-reported and accelerometer-determined PA among the analytic sample are also presented in Table 2. Levels of self-reported MVPA and MV2PA were significantly higher in men than in women (both $p < 0.001$). Similarly, mean values of accelerometer-determined total MVPA and MV2PA, and MVPA and MV2PA in modified 10-minute bouts were all significantly higher in men than in women (all $p < 0.001$).

The proportion of adults self-reporting compliance to the 2008 PAGA was 63.60 ± 0.01%. In contrast, a blind application of the ≥ 150 minutes/week threshold to accelerometer-determined estimates of MV2PA indicate that only 13.50 ± 0.01% of American adults are compliant to the 2008 PAGA.

Table 2

Descriptive Characteristics of the Analyzed Sample

Variables	Men	Women	Combined
N	2,320	2,464	4,784
Age (years)	39.72 ± 0.39	40.08 ± 0.38	39.90 ± 0.35
18-29 (%)	26.74 ± 1.14	25.68 ± 1.13	26.20 ± 0.01
30-39 (%)	22.63 ± 1.14	22.43 ± 1.07	22.53 ± 0.01
40-49 (%)	24.67 ± 1.20	24.96 ± 0.93	24.82 ± 0.01
50-64 (%)	25.96 ± 1.45	26.94 ± 1.32	26.46 ± 0.01
Race/ethnicity			
Non-Hispanic Whites (%)	70.92 ± 2.25	68.54 ± 2.48	69.71 ± 0.02
Non-Hispanic Blacks (%)	11.23 ± 1.47	13.08 ± 1.62	12.17 ± 0.01
Mexican Americans (%)	9.61 ± 1.23	8.25 ± 1.12	8.92 ± 0.01
Other Hispanic (%)	3.02 ± 0.51	4.12 ± 0.59	3.58 ± 0.01
Other (%)	5.23 ± 0.65	6.01 ± 0.86	5.63 ± 0.01
Anthropometrics			
Height (cm)	176.70 ± 0.22	163.02 ± 0.18*	169.83 ± 0.21
Weight (kg)	87.79 ± 0.66	75.05 ± 0.70*	81.32 ± 0.57
BMI (kg/m^2)	28.01 ± 0.20	28.29 ± 0.26	28.12 ± 0.19
BMI-defined Weight Status †			
Underweight (%)	1.76 ± 0.32	2.02 ± 0.31	1.8915 ± 0.01
Normal Weight (%)	28.909 ± 1.49	38.27 ± 1.61	33.6735 ± 0.01
Overweight (%)	38.88 ± 1.38	26.58 ± 1.23	32.62 ± 0.01
Obese (%)	30.45 ± 1.73	33.13 ± 1.48	31.81 ± 0.01
Self-Reported Physical Activity			
MVPA (min/wk)	450.04 ± 17.46	353.29 ± 12.27*	400.8 ± 12.83
MV2PA (min/wk)	534.60 ± 19.23	421.46 ± 13.53*	477.02 ± 13.66
Accelerometer-Determined Physical Activity			
MVPA (min/wk)	243.72 ± 5.53	140.60 ± 4.04*	191.24 ± 4.45
MV2PA (min/wk)	253.70 ± 6.07	146.89 ± 4.37*	199.34 ± 4.83
MVPA in modified 10-minute bouts (min/wk)	64.92 ± 3.57	46.56 ± 2.82*	55.58 ± 2.91
MV2PA in modified 10-minute bouts (min/wk)	72.28 ± 4.20	51.95 ± 3.16*	61.94 ± 3.31

Note. Values weighted to provide nationally representative estimates and presented as percentage or mean ± SE. †Underweight < 18.5 kg/m^2; Normal weight = 18.5-24.9 kg/m^2; Overweight=25.0-29.9 kg/m^2; Obese ≥ 30.0 kg/m^2; MVPA = moderate-to-vigorous physical activity; MV2PA = moderate-to-vigorous physical activity derived after weighting vigorous physical activity (MV2PA = MPA + VPA*2). MPA = moderate-intensity physical activity; VPA = vigorous-intensity physical activity. *$p < 0.001$.

Optimal thresholds of accelerometer-determined MV2PA (in modified 10-minute bouts and in total) predicting self-reported compliance to the 2008 PAGA for the combined sample and separately for men and women are presented in Table 3. ROC curve analyses indicated the optimal threshold of MV2PA in

Table 3

Area Under the Curve (AUC) and Optimal Thresholds From Receiver Operating Characteristic Curve Analyses for the Combined Sample and Each Sex Separately

Sample	Accelerometer-determined minutes/week of MV2PA in modified 10-minute bouts*	Accelerometer-determined minutes/week of total MV2PA*
Combined Sample		
AUC	0.6369 ± 0.0084	0.6283 ± 0.0115
95% CI	0.6209 – 0.6533	0.6063 – 0.6508
Optimal Threshold	13.0 ± 1.69	122.3 ± 4.62
95% CI	11.00 – 17.39	110.51 – 129.51
Sensitivity	0.588	0.647
Specificity	0.633	0.555
Men		
AUC	0.6264 ± 0.0097	0.5946 ± 0.0100
95% CI	0.6077 – 0.6451	0.5752 – 0.6141
Optimal Threshold	26.03 ± 5.35	204.27 ± 9.87
95% CI	16.00 – 34.00	174.00 – 220.01
Sensitivity	0.558	0.555
Specificity	0.643	0.581
Women		
AUC	0.6431 ± 0.0118	0.6588 ± 0.0160
95% CI	0.6202 – 0.6656	0.6280 – 0.6902
Optimal Threshold	0.13 ± 5.70	98 ± 4.13
95% CI	0.00 – 15.00	94.00 – 111.03
Sensitivity	0.545	0.611
Specificity	0.693	0.635

Note. MV2PA = moderate-to-vigorous physical activity derived after weighting vigorous physical activity (MV2PA = MPA + VPA*2). MPA = moderate-intensity physical activity; VPA = vigorous-intensity physical activity.

modified 10-minute bouts was 13.00 ± 1.69 minutes/week, while the optimal threshold of total MV2PA (ignoring the bout criteria) was 122.3 ± 4.62 minutes/week. Both of the aforementioned thresholds are less than the minimum self-reported compliance threshold of 150 minutes/week (both $p < 0.001$). In both instances, MV2PA in modified 10-minute bouts and total MV2PA were significant predictors of self-reported compliance to the 2008 PAGA (both $p < 0.001$). It should be noted, however, that the strength of binary prediction (i.e., self-reported compliance vs. non-compliance to the 2008 PAGA) associated with the objectively identified thresholds of accelerometer-determined MV2PA was somewhat weak as AUC values ranged from 0.63 to 0.64 among the total sample (Table 3 & Figures 1 & 2; Men: AUC = 0.59-0.63; Women: AUC = 0.64-0.66). Moreover, levels of sensitivity and specificity associated with ROC curve analyses were also low among the combined sample and separately for each sex (all < 70%).

Construct validity analyses using multivariable linear and logistic regressions are presented in Table 4. For adjusted analyses concerned with self-reported MV2PA, only glycated hemoglobin was significantly associated with compliance to the 2008 PAGA (0.10 ± 0.03 % lower in compliant adults when compared to non-compliant adults, $p = 0.003$). In contrast, compliance to the 2008 PAGA using the newly identified threshold of 13.0 minutes/week of MV2PA in modified 10-minute bouts was associated with higher HDL cholesterol and lower glycated hemoglobin, SBP, waist circumference, and BMI, and lower risks for hypertension and obesity (all $p < 0.05$). Similarly, compliance to the 2008 PAGA

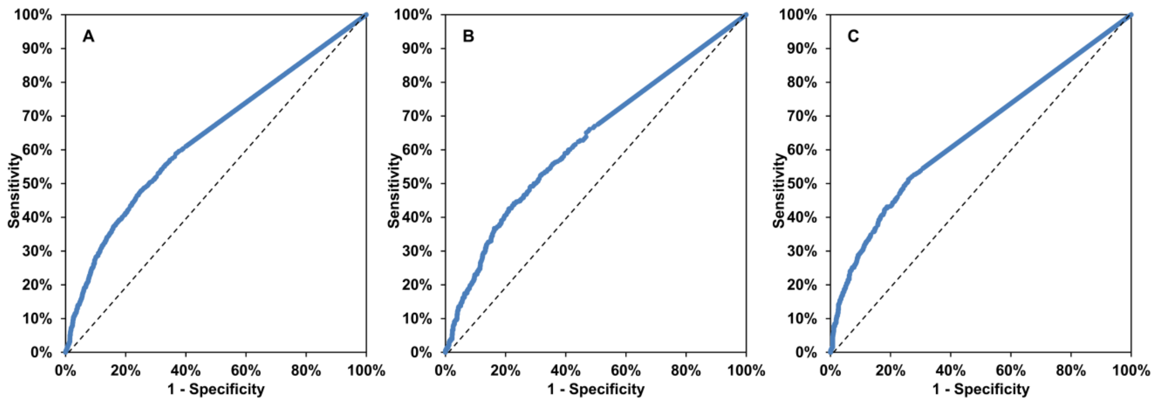

Figure 1. Receiver operating characteristic curves corresponding to the prediction of self-reported compliance to the 2008 Physical Activity Guidelines for Americans via an equivalent combination of weekly accelerometer-determined moderate- and vigorous-intensity physical activity (MV2PA) in modified 10-minute bouts. Data are presented in panels for A) the combined sample, B) men, and C) women. MV2PA calculated as moderate-intensity physical activity (MPA) plus weighted vigorous-intensity physical activity (VPA; MV2PA = MPA + VPA*2).

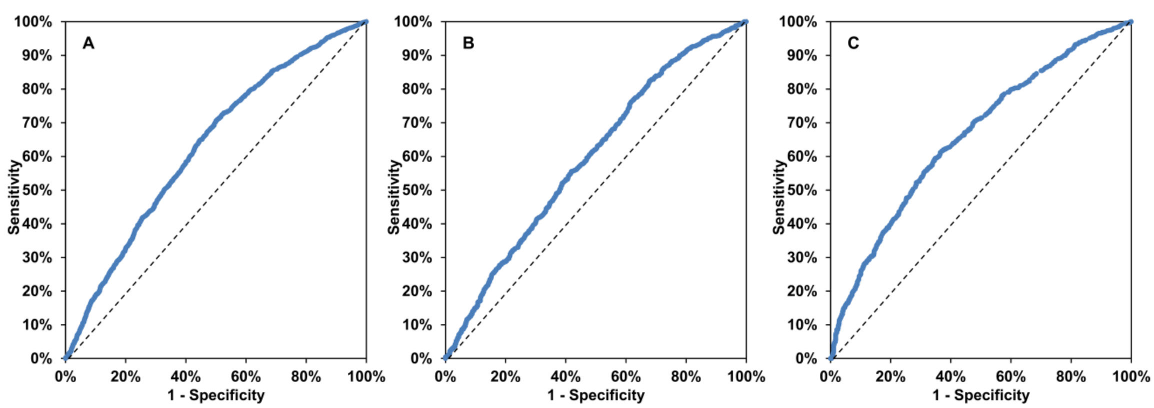

Figure 2. Receiver operating characteristic curves corresponding to the prediction of self-reported compliance to the 2008 Physical Activity Guidelines for Americans via an equivalent combination of total weekly accelerometer-determined moderate- and vigorous-intensity physical activity (MV2PA; no bout requirement). Data are presented in panels for A) the combined sample, B) men, and C) women. MV2PA calculated as moderate-intensity physical activity (MPA) plus weighted vigorous-intensity physical activity (VPA; MV2PA = MPA + VPA*2).

Table 4

Relationships Between Different Indicators of Compliance to Physical Activity Guidelines and Various Cardiometabolic Biomarkers and Disease States.

	≥ 150 Minutes/Week of Self-Reported MV2PA			≥ 13.0 Minutes/Week of Accelerometer-determined MV2PA in 10-minute bouts			≥ 122.3 Minutes/Week of Accelerometer-determined MV2PA		
	%	*SE*	*p*	%	*SE*	*p*	%	*SE*	*p*
Compliance									
Yes	63.6	± 0.01	-	50.6	± 0.01	-	59.2	± 0.01	-
No	36.4	± 0.01	-	49.4	± 0.01	-	40.7	± 0.01	-
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Glycated hemoglobin (%)	-0.10	± 0.03	0.003	-0.08	± 0.03	0.016	-0.16	± 0.03	< 0.001
Fasting plasma glucose (mg/dl)	-2.35	± 1.87	0.222	-1.93	± 1.77	0.288	-4.75	± 1.64	0.009
Triglycerides (mg/dl)	-27.42	± 26.89	0.320	-37.55	± 18.39	0.055	-61.03	± 27.08	0.036
LDL (mg/dl)	2.99	± 5.15	0.567	-1.09	± 4.33	0.804	3.19	± 4.43	0.479
HDL (mg/dl)	-0.01	± 1.32	0.998	3.97	± 1.38	0.009	3.68	± 1.78	0.051
SBP (mmHg)	-1.03	± 0.75	0.187	-2.60	± 0.88	0.008	-2.99	± 1.09	0.012
DBP (mmHg)	-0.83	± 0.65	0.144	-0.94	± 0.63	0.146	-0.67	± 0.75	0.384
Waist circumference (cm)	-1.95	± 1.07	0.081	-4.45	± 0.85	< 0.001	-6.46	± 0.85	< 0.001
BMI (kg/m^2)	-0.65	± 0.50	0.205	-1.44	± 0.36	< 0.001	-2.28	± 0.41	< 0.001
	OR (95% CI)		*p*	OR (95% CI)		*p*	OR (95% CI)		*p*
Hypertension	0.95 (0.75, 1.19)		0.650	0.68 (0.53, 0.88)		0.008	0.60 (0.47, 0.78)		< 0.001
Hyperlipidemia	1.15 (0.63, 2.08)		0.662	1.23 (0.81, 1.89)		0.342	0.97 (0.61, 1.53)		0.893
Obesity	0.85 (0.63, 1.16)		0.315	0.66 (0.50, 0.87)		0.007	0.47 (0.38, 0.60)		< 0.001
Impaired fasting glucose	0.97 (0.67, 1.42)		0.893	0.74 (0.52, 1.05)		0.105	0.61 (0.43, 0.88)		0.014
Diabetes mellitus	0.86 (0.48, 1.53)		0.610	0.60 (0.28, 1.30)		0.212	0.32 (0.15, 0.65)		0.005

Notes. Betas (*b*) and standard errors (*SE*) derived from linear regression models. Odds ratios (OR) derived from logistic regression models. All linear and logistic regression models were adjusted for age, sex, education level, smoking status, and employment status. LDL = low-density lipoprotein; HDL = high-density lipoprotein; SBP = systolic blood pressure; DBP = diastolic blood pressure; BMI = body mass index. MV2PA calculated as moderate-intensity physical activity (MPA) plus weighted vigorous-intensity physical activity (VPA; MV2PA = MPA + VPA*2).

using the total MV2PA threshold of 122.3 minutes/week was associated with lower glycated hemoglobin, fasting plasma glucose, triglycerides, SBP, waist circumference, BMI, and lower risks for hypertension, obesity, impaired fasting glucose, and diabetes mellitus.

Results of sensitivity analyses examining the effect of different MVPA activity count cut-points on identified thresholds of accelerometer-determined MV2PA corresponding to self-reported compliance to the 2008 PAGA are depicted in Figures 3 and 4. As previously mentioned, the zero-inflated and right-skewed distributions of accelerometer-determined MV2PA estimates made linear and poisson regression approaches to threshold identification untenable. As such, results presented in Figures 3 and 4 were derived using a series of ROC curve analyses; however, we only present accelerometer-determined thresholds corresponding to self-reported compliance to the 2008 PAGA for those activity count-defined estimates of MV2PA which produced AUC estimates ≥ 0.6. For accelerometer-determined MV2PA in modified 10-minute bouts, optimal thresholds associated with self-reported compliance to the 2008 PAGA ranged from 0.03 to 58.8 minutes/week with a significant amount of variability noted between the nine estimates (Figure 3). For total accelerometer-determined MV2PA, optimal thresholds associated with self-reported compliance to the 2008 PAGA ranged from 22.5 to 166.7 minutes/week (Figure 4). Similar to MV2PA in modified 10-minute bouts, significant variability was observed between the eight estimates.

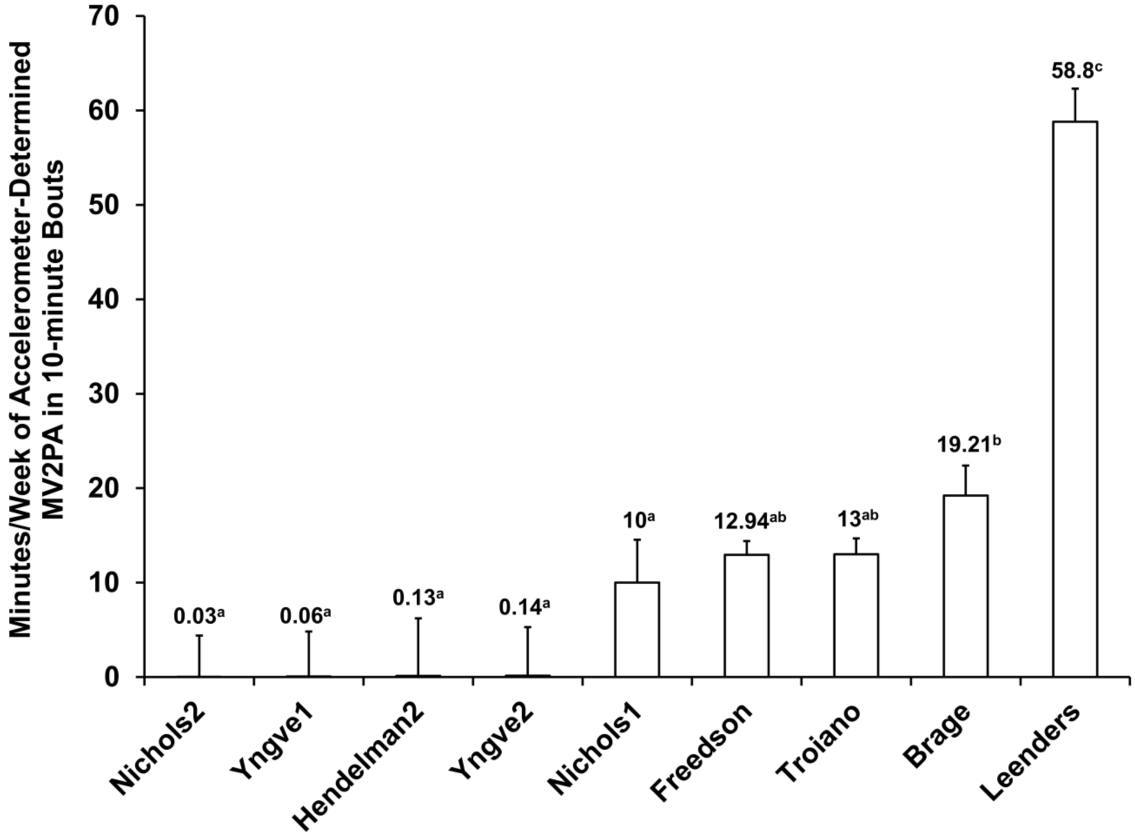

Figure 3. Sensitivity analysis comparing optimal accelerometer-determined moderate- and vigorous-intensity physical activity (MV2PA) in 10-minute bouts corresponding to self-reported compliance to the 2008 Physical Activity Guidelines for Americans. Values derived using receiver operating characteristic (ROC) curve analysis. Error bars represent standard errors estimated using the (n-1) bootstrap. MV2PA calculated as moderate-intensity physical activity (MPA) plus weighted vigorous-intensity physical activity (VPA; MV2PA = MPA + VPA*2). Nichols2 = Nichols et al., 2000; Yngve1= Yngve et al., 2003; Hendelman2= Hendelman et al., 2000, Yngve2= Yngeye et al., 2003 Nichols1= Nichols et al., 2000; Freedson= Freedson et al., 1998; Troiano= Troiano et al., 2008; Brage et al., 2003; Leedners et al., 2003. Values with different superscript letters are significantly different at $p < 0.001$.

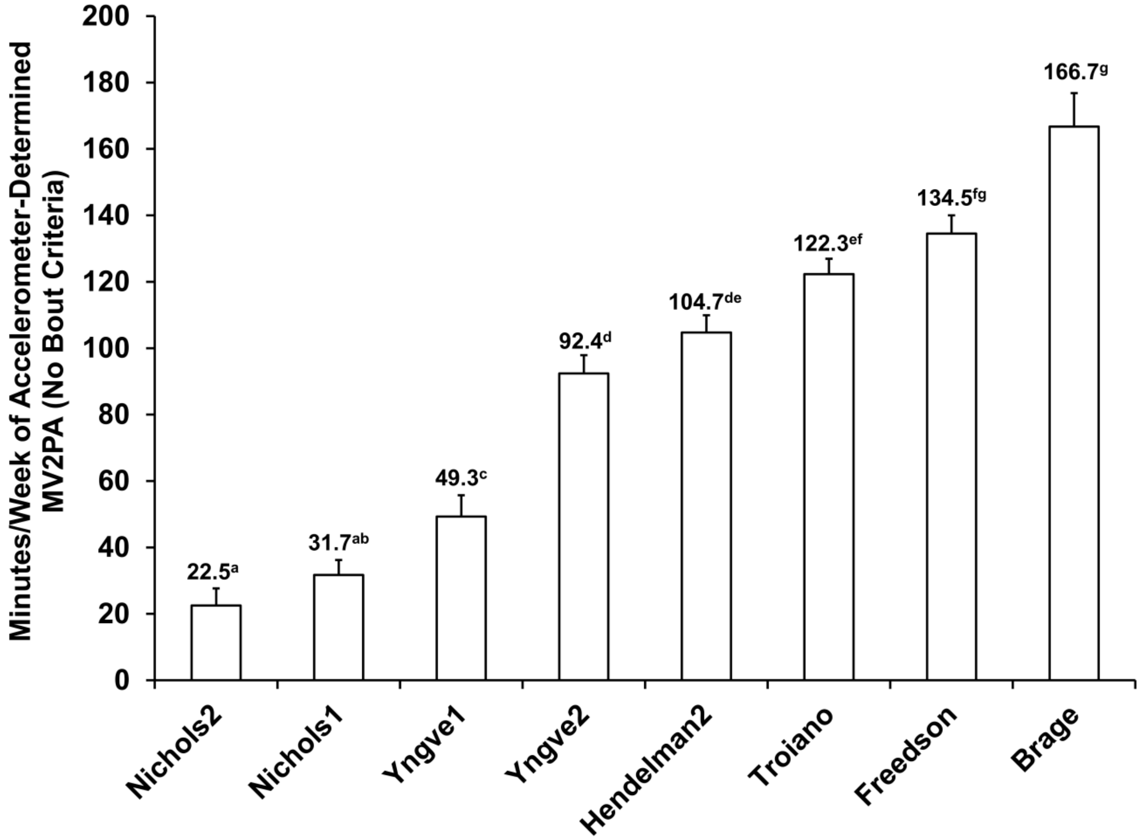

Figure 4. Sensitivity analysis comparing optimal accelerometer-determined moderate- and vigorous-intensity physical activity (MV2PA; no bout criteria) corresponding to self-reported compliance to the 2008 Physical Activity Guidelines for Americans. Values derived using receiver operating characteristic (ROC) curve analysis. Error bars represent standard errors estimated using the (n-1) bootstrap. MV2PA calculated as moderate-intensity physical activity (MPA) plus weighted vigorous-intensity physical activity (VPA; MV2PA = MPA + VPA*2). Nichols1 = Nichols et al., 2000; Nichols2 = Nichols et al., 2000; Yngve1= Yngve et al., 2003; Yngve2= Yngeye et al., 2003; Hendelman2= Hendelman et al., 2000; Troiano= Toiano et al., 2008; Freedson= Freedson et al., 1998; Brage et al., 2003. Values with different superscript letters are significantly different at $p < 0.001$.

Chapter 5. Discussion

The primary aim of this study was to calculate thresholds of accelerometer-determined MV2PA that correspond to self-reported compliance to the 2008 PAGA. We also evaluated the classification accuracy and construct validity of optimal accelerometer-determined thresholds and analyzed the effects of different activity count cut-points on threshold values of accelerometer-determined PA corresponding to self-reported compliance to the 2008 PAGA.

Newly identified optimal thresholds of accelerometer-determined MV2PA corresponding to self-reported compliance to the 2008 PAGA were significantly less than 150 minutes/week, with a threshold of 13.0 minutes/week for MV2PA in modified 10-minute bouts and a total MV2PA threshold (no bout criteria) of 122.3 minutes/week. Similarly, mean values of 10-minute bout accumulated accelerometer-determined MV2PA were significantly less than self-reported MV2PA estimates (61.94 ± 3.31 vs. 447.02 ± 13.66 minutes/week, respectively). This is consistent with results from analyses by several previous reports from Troiano et al. (2008), Tucker et al. (2011), and Schuna et al. (2013) and further exemplifies the discordance between self-reported and accelerometer-determined estimates of PA. It is also important to note that the newly determined optimal threshold of accelerometer-determined MV2PA in 10-minute bouts is less than one-tenth as large (13.0 minutes/week of MV2PA) as the current 150 minutes/week guideline. This amount of activity (13.0 minutes/week of MV2PA) is dramatically smaller than previously proposed guidelines and would theoretically be considered more attainable. Published estimates of accelerometer-determined compliance to current PA guidelines are extremely low with results from Troiano et al. (2008) and Tucker et al. (2011) indicating that approximately 3.0% and 9.6% of American adults, respectively, are accumulating the recommended amount of weekly PA. Our results indicating that 50.6% of American adults accumulate ≥ 13.0 minutes/week of accelerometer-determined MV2PA in 10-minute bouts illustrates how the newly identified threshold may be more attainable than the current guideline of ≥ 150 minutes/week.

ROC curve analyses indicated that accelerometer-determined MV2PA in 10-minute bouts and total MV2PA were significant predictors of self-reported compliance to the 2008 PAGA (both AUCs > 0.50). However, further evaluation of the fitted ROC curve models suggested that accelerometer-determined MV2PA, whether in 10-minute bouts or in total, had less than desirable levels of classification accuracy when used as the sole predictor of self-reported compliance to the 2008 PAGA (≥ 150 minutes/week of MV2PA). Our observed maximum sensitivity values were 58% and 65% for 10-minute bout and total MV2PA while specificity values were 63% and 55%, respectively. All sensitivity and specificity values from models evaluated herein were less than our *a priori* defined standard of 80%. However, it should be noted that the proportion of individuals meeting guidelines when classified using the newly identified thresholds of accelerometer-determined PA (50.6% compliant: 13.0 minutes/week for MV2PA in modified 10-minute bouts; 59.2% compliant: 122.3 minutes/week for a total MV2PA) are relatively more proportional to those commonly obtained via self-report. Although self-reported compliance to the 2008 PAGA (≥ 150 minutes/week of MV2PA) was 63.6% herein, and accelerometer-determined estimates indicate compliance rates of only 13.5%, these estimates are somewhat higher than those previously reported in other investigations (62.0% for self-report and 9.6% for accelerometer; Tucker et al. [2011], 51% for self-report and < 5% for accelerometer; Troiano et al. [2008]). This is primarily due to the selected sample, which excluded older adults (> 64 years old) who tend to have the lowest levels of PA (Johannsen et al., 2008; Sparling, Howard, Dunstan, & Owen, 2015; Troiano et al., 2008) and hence compliance (Tucker et al., 2011).

In addition, our latter hypothesis that compliance to the newly identified accelerometer-determined thresholds of MV2PA, and self-reported compliance to the 2008 PAGA, would demonstrate similar relationships with various anthropometric and cardiometabolic biomarkers was not supported by the results herein. This conclusion is supported by the large discrepancy regarding the number of outcome variables significantly associated with each metric (i.e., self-reported MV2PA: 1 significant association; 13.0 min/week of accelerometer-determined MV2PA [in 10-minute bouts]: 7 significant associations; 122.3 min/week of accelerometer-determined MV2PA [no bout requirement]: 10 significant associations). These results emphasize information provided by previous research that objective measures of PA are typically more significant predictors of health than subjective measures of PA (Atienza et al., 2011; Celis-Morales et al., 2012). Similar to our results herein, recent research by Tucker, Welk, Beyler, and Kim (2016) also concluded that objective estimates of PA tend to be more strongly associated with indices of cardiovascular risk when compared to self-report measures. Relationships between accelerometer PA and other metabolic syndrome risk factors were largely impacted when BMI was controlled for in analyses suggesting to researchers that PA may impact cardiovascular risk, in part, through its beneficial effect on weight management. Due to the cross-sectional nature of this research, however, it is difficult to delineate the true impact of body mass on this relationship (Tucker et al., 2016). Other research conducted by Loprinzi and Pariser (2013) utilizing the same data set (NHANES 2003-2006), investigated whether or not accelerometer-determined PA displayed a stronger independent association with various cardiometabolic biomarkers than self-reported PA among individuals with diabetes. This research suggested that similar relationships found by other researchers in the general population (i.e., accelerometer-determined PA is more strongly associated with health outcomes than self-reported PA) may also be evident in chronic disease populations.

The last component of the secondary data analysis detailed herein evaluated the potential for variability in optimal accelerometer-determined thresholds of MV2PA based on different choices of activity counts/minute cut-points used in quantifying MPA and VPA. Obtained results were consistent with our *a priori* hypothesis as identified accelerometer-determined MV2PA thresholds corresponding to self-reported compliance to the 2008 PAGA significantly varied as a function of the chosen MPA and VPA activity counts/minute cut-points. For analyses used to identify optimal thresholds of accelerometer-determined MV2PA that correspond to self-reported compliance to the 2008 PAGA in aims 1 and 2 detailed above, we chose to utilize the Troiano cut-points (i.e., 2,020 ≤ MPA < 5,999 activity counts/minute and VPA ≥ 5,999 activity counts/minute) based on their extensive support in the empirical literature base (Tudor-Locke, Camhi, & Troiano, 2012). Despite the lack of studies indicating which cut-point value is superior (Loprinzi et al., 2012; Rothney et al., 2008; Watson, Carlson, Carroll, & Fulton, 2014), a clustering of optimal MV2PA thresholds can be observed in Figures 3 & 4 between the Freedson, Troiano, and Brage cut-points. It should be noted, however, that MV2PA estimates using the Swartz and Hendelman1 cut-points for 10-minute bout quantifications as well as the Leenders, Swartz, and Hedelman1 cut-points for total MV2PA, provided little (AUC < 0.6) or no predictive value (AUC = 0.50) toward identifying self-reported compliance to the 2008 PAGA. Overall, different cut-points used to estimate levels of MV2PA created large variation in the ability to predict self-reported MV2PA and compliance to the 2008 PAGA (Loprinzi et al., 2012; Rothney et al., 2008; Watson et al., 2014).

In addition to variability in results due to using numerous activity count cut-points, investigation of accelerometer data in "accumulated bouts" (e.g., the 10-minute bouts described herein) has been limited and there remains no consensus around the potential health benefits of shorter bouts vs longer bouts of PA spread throughout the day (Barr-Anderson, AuYoung, Whitt-Glover, Glenn, & Yancey, 2011; Physical Activity Guidelines Advisory Committee, 2008). The portion of the 2008 PAGA that suggests a continuous aerobic activity should last 10 minutes or more in duration has only been examined in limited randomized controlled trials (Dunn et al., 1999; Jakicic, Wing, Butler, & Robertson, 1995), which calls into question this criteria's validity and relevance to PA guidelines (DeBusk, Stenestrand, Sheehan, & Haskell, 1990; Ebisu, 1985; Jakicic et al., 1995). Due to lack of congruity between research methods and longitudinal comparison between distinctly different exercise approaches, there is still no clear answer as to whether or not how an individual accumulates PA significantly impacts their overall health. It is also unclear what impact bout duration has on major clinical outcomes, such as all-cause mortality and other debilitating chronic diseases, due to limitations of the questionnaires utilized in most prospective observational studies which underpin the 2008 PAGA (Physical Activity Guidelines Advisory Committee, 2008). Although current information regarding the impact of shorter bouts of PA is limited, a foundation has been set for the idea that the total accumulation of PA is of greatest concern and individuals should be encouraged to obtain PA in increased frequency and duration when possible (Glazer et al., 2013; Strath, Holleman, Richardson, Ronis, & Swartz, 2008).

Analyses utilizing large data sets such as the Framingham Heart Study (Glazer et al., 2013) and NHANES (Strath et al., 2008) show that objectively measured MVPA accumulated in < 10-minute bouts are cross-sectionally related to a lower CVD risk factor burden and independently associated with BMI and waist circumference. Research from Glazer et al. (2013) examined total and shorter bouts of MVPA and found that both metrics were significantly related to blood lipids, BMI, waist circumference, and Framingham risk score ($p < 0.001$). Data such as this lend support to notions that the 10-minute bout criteria may not be necessary to achieve substantial health benefits when accumulating PA.

Moreover, research examining how practitioners and exercise professionals relay the 2008 PAGA to end users suggests that the 10-minute bout criteria is most likely not acknowledged or even clearly understood (Zenko & Ekkekakis, 2015). With this information in mind, the 10-minute bout criteria for MV2PA associated with the 2008 PAGA should be further examined to evaluate its public health importance (Joy, Blair, McBride, & Sallis, 2012).

In contrast, a number of studies indicate that total PA may actually have an equal or greater impact on overall fitness than PA specifically accumulated in bouts (Loprinzi & Cardinal, 2013; Murphy, Nevill, & Hardman, 2000; Murtagh, Boreham, Nevill, Hare, & Murphy, 2005; Quinn, Klooster, & Kenefick, 2006; Wolff-Hughes et al., 2015). Interestingly, research conducted by Loprinzi and Cardinal (2013) using NHANES 2003-2006 data yielded similar results to ours regarding the relationships between anthropometric and cardiometabolic health outcomes and total MVPA and MVPA accumulated in 10-minute bouts. Although the authors found favorable independent relationships between various health outcomes and both MVPA accumulation patterns, there was little to no significant difference in the impact of bout vs non-bout activity. This research is consistent with other similar analyses (Powell, Paluch, & Blair, 2011; Strath et al., 2008; Wolff-Hughes et al., 2015), and along with our results, lend favor to promoting overall active lifestyles in contrast to concerning the public with concepts of aerobic activity bouts as specified in the 2008 PAGA.

Our sensitivity analyses examining the output of newly identified MV2PA thresholds consistent with compliance to the 2008 PAGA yielded some interesting results. We found significant variability in optimal thresholds corresponding to compliance with PA guidelines, depending on the specific activity count/minute cut-points used to quantify MV2PA. The two cut-points of primary focus here were the Freedson et al. (1998) and Troiano et. al (2008) cut-points which are both depicted in Figures 3 & 4. These cut-points are the most widely used throughout the PA research literature base and show consistency in their measurability. A recent publication count using the database *Web of Science* indicates that there were approximately 1,121 and 2,133 citations of the Freedson et al. and Troiano et al. publications, respectively (Conducted on June 5, 2016). In regard to these two sets of cut-points, we observed little variability in compliance estimates for MV2PA accumulated in 10-minute bouts and in total.

This study was not without limitations. As with similar cross-sectional studies, we are unable to make causal inferences regarding the application of our findings. It is important to note that when utilizing accelerometer data of this nature, there is a certain amount of error expected due to the lack of consensus on how to best process waist-worn accelerometer data (Freedson et al., 2012; Troiano et al., 2014). Although no consensus regarding the processing of accelerometry data currently exists, our research herein can be replicated using the described data reduction and analysis techniques. An additional limitation of the research herein includes our inability to implement appropriate multiple regression analyses while attempting to identify optimal thresholds due to a lack of developed statistical theory which incorporates appropriate adjustment for zero inflation within the framework of complex survey data analysis. Moreover, the utilization of PA data derived via self-report presents innate limitations due to its extremely variable nature (Sallis & Saelens, 2000).

Conversely, there were major strengths to this research allowing it to contribute considerably to the body of literature investigating the 2008 PAGA. This analysis included the use of a nationally representative sample of U.S. adults, using a subset of NHANES objectively and subjectively measured PA data while controlling for important confounding variables. Additionally, this examination strived toward closing an existing methodological gap with the hopes our research will spur future development of objectively based PA guidelines sometime in the near future. Overall the novel analysis conducted here has provided a glimpse of what future PA guidelines derived from objective measurements could look like as a means to accurately capture and recommend PA for the U.S. adult population.

Future epidemiological and clinical research is needed to aid the development of PA guidelines informed by accelerometer-determined estimates of PA. There are ongoing longitudinal prospective cohort studies, such as the Healthy Woman's Study (Pettee Gabriel et al., 2013) and Coronary Artery Risk Development in Young Adults study (Gordon-Larsen et al., 2009), which have implemented accelerometry into their PA assessment protocols. Results from these studies will undoubtedly play a vital role in improving our understanding of the links between accelerometer-determined PA and health.

Chapter 6. Conclusion

In summary, this study utilized data from the 2003-2006 NHANES to identify accelerometer-determined thresholds of MV2PA that correspond with self-reported compliance to the 2008 PAGA (≥ 150 minutes/week of MV2PA). Although these data are somewhat dated and have been previously utilized to answer a variety of PA-related epidemiological research questions, no newer nationally representative data source exists that would allow for the investigation of the aims outlined herein.

An innovative attempt to quantify thresholds of accelerometer-determined MV2PA consistent with self-reported compliance to the 2008 PAGA was accomplished via use of ROC curve analyses. Our newly calculated thresholds for MV2PA were 13.00 ± 1.69 minutes/week in modified 10-minute bouts and 122.30 ± 4.62 minutes/week in total (no bout requirement). As previously mentioned, 10-minute bout and total estimates of weekly accelerometer-determined MV2PA corresponding to self-reported compliance to the 2008 PAGA were significantly less than the ≥ 150 minutes/week criteria. Furthermore, additional analyses indicated that meeting or exceeding these newly identified accelerometer-determined thresholds may provide greater health benefits than achieving the self-reported guideline of ≥ 150 minutes/week of MV2PA. Follow-up analyses using different activity counts/minute cut-points for MPA and VPA produced a wide range of optimal thresholds for MV2PA in 10-minute bouts (0.03 to 58.8 minutes/week) and in total (22.5 to 166.7 minutes/week) consistent with self-reported compliance to the 2008 PAGA. However, it is worth noting that minimal variability in optimal accelerometer-determined MV2PA estimates was observed between the two most commonly used sets of activity counts/minute cut-points (i.e., Freedson and Troiano cut-points).

Overall, the findings and analyses we have presented herein are novel. Future epidemiological and clinical research is needed to build upon and augment the analyses, results, and conclusions we present. The ultimate realization of these labors will hopefully result in the creation of PA guidelines derived by accelerometer-determined estimates of PA.

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APPENDICES

Appendix A. Institutional Review Board Determination

Institutional Review Board
Office of Research Integrity | Oregon State University
B308 Kerr Administration Building, Corvallis, OR 97331-2140
Telephone (541) 737-8008
irb@oregonstate.edu | http://research.oregonstate.edu/irb

RESEARCH DETERMINATION

Date of Notification	03/13/2015		
Study ID	6757		
Study Title	Identifying objectively monitored moderate to vigorous physical activity thresholds that correspond to self-reported compliance with physical activity guidelines: National Health and Nutrition Examinaiton Survey (NHANES) 2003 2006		
Person Submitting Form	Julie Brier		
Principal Investigator	Dr. John Schuna		
Study Team Members	Julie Brier		
Funding Source	None	Proposal #	N/A
PI on Grant or Contract	N/A	Cayuse #	N/A

The above referenced submission was reviewed by the OSU Institutional Review Board (IRB).

DETERMINATION: IRB REVIEW NOT REQUIRED

The above referenced proposal was reviewed by the OSU Institutional Review Board (IRB) Office. The IRB has determined that your project, as submitted, DOES NOT meet the definition of research involving human subjects under the regulations set forth by the Department of Health and Human Services 45CFR46.102.

OSU IRB review is not required.

Please note that amendments to this project may impact this determination.

The federal definitions and guidance used to make this determination may be found at the following links:

Research

Human Subject

Institutional Engagement

Appendix B. NHANES Physical Activity Questionnaire

2003-04 Questionnaire

PHYSICAL ACTIVITY AND PHYSICAL FITNESS - PAQ_C

BOX 1A
CHECK ITEM PAQ.005: IF SP AGE >= 16, CONTINUE. OTHERWISE, GO TO BOX 6.

PAQ.020 The next series of questions are about physical activities that {you/SP} {have/has} done over the **past 30 days**. First I will ask about activities that are related to transportation. Then I'll ask about {your/his/her} daily activities, and finally, about physical activities that {you do/he/she does} in {your/his/her} leisure time.

Over the **past 30 days**, {have/has} {you/SP} walked or bicycled as part of getting to and from work, or school, or to do errands?

CODE 'UNABLE TO DO' ONLY IF RESPONDENT VOLUNTEERS

YES 1
NO 2 (PAQ.100)
UNABLE TO DO ACTIVITY 3 (PAQ.100)
REFUSED 7 (PAQ.100)
DON'T KNOW... 9 (PAQ.100)

PAQ.050 [Over the **past 30 days**], how often did {you/SP} do this? [Walk or bicycle as part of getting to and from work, or school, or to do errands.]
PROBE: How many times per day, per week, or per month did {you/s/he} do these activities?

|___|___|___|
ENTER NUMBER OF TIMES (PER DAY, WEEK OR MONTH)

REFUSED 777 (PAQ.100)
DON'T KNOW... 999 (PAQ.100)

ENTER UNIT

DAY 1
WEEK 2
MONTH 3
REFUSED 7 (PAQ.100)
DON'T KNOW... 9 (PAQ.100)

PAQ.080 On those days when {you/SP} walked or bicycled, about how long did {you/s/he} spend altogether doing this?

|___|___|___|
ENTER NUMBER (OF MINUTES OR HOURS)

REFUSED 777
DON'T KNOW... 999

ENTER UNIT

MINUTES 1
HOURS... 2
REFUSED 7
DON'T KNOW... 9

PAQ.100 Over the **past 30 days**, did {you/SP} do any tasks in or around {your/his/her} home or yard for **at least 10 minutes** that required moderate or greater physical effort? By moderate physical effort I mean, tasks that caused **light** sweating or a **slight to moderate increase** in {your/his/her} heart rate or breathing. such as raking leaves, mowing the lawn or heavy cleaning.

CODE 'UNABLE TO DO' ONLY IF RESPONDENT VOLUNTEERS

YES 1
NO 2 (PAQ.180)
UNABLE TO DO ACTIVITY........................... 3 (PAQ.180)
REFUSED 7 (PAQ.180)
DON'T KNOW... 9 (PAQ.180)

PAQ.120 [Over the **past 30 days**], how often did {you/SP} do **these tasks** in or around {your/his/her} home or yard, that is tasks requiring at least moderate effort? [Such as raking leaves, mowing the lawn or heavy cleaning]
PROBE: How many times per day, per week, or per month did {you/s/he} do these activities?

|___|___|___|
ENTER NUMBER OF TIMES (PER DAY, WEEK OR MONTH)

REFUSED 777 (PAQ.180)
DON'T KNOW... 999 (PAQ.180)

ENTER UNIT

DAY 1
WEEK... 2
MONTH 3
REFUSED 7 (PAQ.180)
DON'T KNOW... 9 (PAQ.180)

PAQ.160 About how long did {you/SP} do these tasks **each time**?

IF MORE THAN 1 TASK, ASK FOR TASK DONE MOST OFTEN

|___|___|___|
ENTER NUMBER (OF MINUTES OR HOURS)

REFUSED 777
DON'T KNOW.. 999

ENTER UNIT

MINUTES 1
HOURS... 2
REFUSED 7
DON'T KNOW.. 9

PAQ.180 Please tell me which of these four sentences **best** describes {your/SP's} usual daily activities? [Daily activities may include {your/his/her} work, housework if {you are/s/he is} a homemaker, going to and attending classes if {you are/s/he is} a student, and what {you/s/he} normally {do/does} throughout a typical day if {you are/he/she is} a retiree or unemployed.] . . .

HAND CARD PAQ1

{You sit/He/She sits} during the day and {do/does} not walk about very much; 1
{You stand or walk/He/She stands or walks} about quite a lot during the day, but {do/does} not have to carry or lift things very often; 2
{You lift or carry/He/She lifts or carries} light loads, or {have/has} to climb stairs or hills often; or 3
{You do/He/She does} heavy work or {carry/carries} heavy loads.................................... 4
REFUSED 7
DON'T KNOW.. 9

PAQ.206 The next questions are about physical activities including exercise, sports, and physically active hobbies that {you/SP} may have done in {your/his/her} leisure time or at school over the **past 30 days**.

First I will ask you about **vigorous** activities that cause **heavy** sweating or **large increases** in breathing or heart rate. Then I will ask you about **moderate** activities that cause only **light** sweating or a **slight to moderate increase** in breathing or heart rate.

Over the **past 30 days**, did {you/SP} do any **vigorous** activities for **at least 10 minutes** that caused **heavy** sweating, or **large increases** in breathing or heart rate? Some examples are running, lap swimming, aerobics classes or fast bicycling. Here are some other examples of these types of activities. Please do not include house work or yard work that you have already told me about.

HAND CARD PAQ2

CODE 'UNABLE TO DO' ONLY IF RESPONDENT VOLUNTEERS

YES	1	
NO	2	(PAQ.326)
UNABLE TO DO ACTIVITY	3	(PAQ.326)
REFUSED	7	(PAQ.326)
DON'T KNOW	9	(PAQ.326)

PAQ.221 [Over the **past 30 days**], what **vigorous** activities did {you/SP} do?

CODE ALL THAT APPLY

AEROBICS (HIGH IMPACT, E.G., STEP, TAEBO)	10
BASKETBALL	12
BICYCLING	13
FOOTBALL	17
HIKING	20
HOCKEY	21
JOGGING	23
KAYAKING	24
RACQUETBALL	26
ROLLERBLADING	27
ROWING	28
RUNNING	29
SKATING	31
SKIING – CROSS COUNTRY (INCLUDING NORDIC TRACK)	32
SKIING – DOWNHILL	33
SOCCER	34
STAIR CLIMBING	36
SWIMMING	38
TENNIS	39
TREADMILL	40
VOLLEYBALL	41
BOXING	50
MARTIAL ARTS (KARATE, JUDO)	53
WRESTLING	54
OTHER (SPECIFY) ________________	71
OTHER (SPECIFY) ________________	72

OTHER (SPECIFY) ________________... 73
REFUSED 77
DON'T KNOW.. 99

BOX 1B

LOOP 1:
ASK PAQ.281 AND PAQ.300 FOR EACH ACTIVITY ENTERED IN PAQ.221.

PAQ.281 [Over the **past 30 days**], how often did {you/SP} {ACTIVITY}?
PROBE: How many times per day, per week, or per month?

CAPI INSTRUCTION:
FILLS FOR ACTIVITY SHOULD BE AS FOLLOWS: 10. do aerobics, 12. play basketball, 13. bicycle, 17. play football, 20. hike, 21. play hockey, 23. jog, 24. kayak, 26. play racquetball, 27. rollerblade, 28. row, 29. run, 31. skate, 32. cross country ski (use the Nordic Track), 33. downhill ski, 34. play soccer, 36. climb stairs, 38. swim, 39. play tennis, 40. use a treadmill, 41. play volleyball, 50. box, 53. practice martial arts, 54. wrestle, 71. DISPLAY ACTIVITY IN 'OTHER SPECIFY', 72. DISPLAY ACTIVITY IN 'OTHER SPECIFY', 73. DISPLAY ACTIVITY IN 'OTHER SPECIFY'.

|___|___|___|
ENTER NUMBER OF TIMES (PER DAY, WEEK OR MONTH)

REFUSED 777
DON'T KNOW.. 999

ENTER UNIT

DAY 1
WEEK.. 2
MONTH 3
REFUSED 7
DON'T KNOW.. 9

PAQ.300 [Over the **past 30 days**], on average about how long did {you/SP} {ACTIVITY} **each time**?

|___|___|___|
ENTER NUMBER (OF MINUTES OR HOURS)

REFUSED 777
DON'T KNOW..999

ENTER UNIT

MINUTES 1
HOURS.. 2
REFUSED 7
DON'T KNOW.. 9

BOX 2

END LOOP 1:
ASK PAQ.281 AND PAQ.300 FOR NEXT ACTIVITY.
IF NO NEXT ACTIVITY, CONTINUE WITH PAQ.326.

PAQ.326 [Over the **past 30 days**], did {you/SP} do **moderate** activities for **at least 10 minutes** that cause only **light** sweating or a **slight to moderate increase** in breathing or heart rate? Some examples are brisk walking, bicycling for pleasure, golf, or dancing. Here are some other examples of these types of activities. Please do not include house work or yard work that you have already told me about.

HAND CARD PAQ3

CODE 'UNABLE TO DO' ONLY IF RESPONDENT VOLUNTEERS

YES	1	
NO	2	(PAQ.440)
UNABLE TO DO ACTIVITY	3	(PAQ.440)
REFUSED	7	(PAQ.440)
DON'T KNOW	9	(PAQ.440)

PAQ.341 [Over the past 30 days], what **moderate** activity or activities did {you/SP} do?

CODE ALL THAT APPLY

AEROBICS (LOW IMPACT)	10
BASEBALL	11
BASKETBALL	12
BICYCLING	13
BOWLING	14
DANCE	15
FISHING	16
FOOTBALL	17
GOLF	19
HIKING	20
HOCKEY	21
HUNTING	22
JOGGING	23
KAYAKING	24
ROLLERBLADING	27
ROWING	28
SKATING	31
SKIING – DOWNHILL	33
SOCCER	34
SOFTBALL	35
STAIR CLIMBING	36
STRETCHING	37
SWIMMING	38
TENNIS	39
TREADMILL	40
VOLLEYBALL	41
WALKING	42
WEIGHT LIFTING	43
FRISBEE	51
HORSEBACK RIDING	52

MARTIAL ARTS (KARATE, JUDO)	53	
YOGA	55	
OTHER (SPECIFY) ___________________...	71	
OTHER (SPECIFY) ___________________...	72	
OTHER (SPECIFY) ___________________...	73	
REFUSED	77	(PAQ.440)
DON'T KNOW..	99	(PAQ.440)

PAQ.591 Now I will ask you about TV watching and computer use.

Over the **past 30 days**, on average how many hours per day did {you/SP} sit and watch TV or videos {outside of work}? Would you say . . .

less than 1 hour,	0
1 hour,	1
2 hours,	2
3 hours,	3
4 hours, or	4
5 hours or more, or	5
{none/you do/SP does not watch TV or videos or use computers outside of work}	8
REFUSED	77
DON'T KNOW	99

CAPI INSTRUCTION:
{outside of work} {you do/SP does not watch TV or videos outside of work} = SP AGE =>16
{none} = SP AGE = 2-11

PAQ.601 Over the **past 30 days**, on average how many hours per day did {SP} use a computer or play computer games {outside of work}? Would you say . . .

less than 1 hour,	0
1 hour,	1
2 hours,	2
3 hours,	3
4 hours, or	4
5 hours or more, or	5
{none/you do/SP does not use a computer outside of work}	8
REFUSED	77
DON'T KNOW	99

CAPI INSTRUCTION:
{outside of work} {you do/SP does not use a computer outside of work} = SP AGE =>16
{none} = SP AGE = 2-11