Physical activity levels and cardiovascular disease risk among U.S. adults: comparison between self-reported and objectively measured physical activity

by

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INTRODUCTION

Physical activity (PA) is one of the most important lifestyle behaviors people can perform to improve their health (1). The literature strongly supports an inverse, dose-response relationship between PA and several diseases and health problems including coronary heart disease, stroke, type 2 diabetes, osteoporosis, depression, some cancers, and all-cause mortality (2). Furthermore, many of these reduced risks have been demonstrated across ethnicities and age groups, including children and adolescents (3-9). Due to these numerous health benefits, substantial efforts have been made to promote PA in the U.S. population. Recently, the U.S. Department of Health and Human Services released the first set of official U.S. physical activity guidelines (Physical Activity Guidelines for Americans - PAGA) (10). The PAGA provide updated evidence regarding PA and health as well as specific recommendations for how much physical activity is needed by different segments of the population.

Not surprisingly, conclusions from the PAGA advisory committee confirmed the importance of PA for individuals of all ages, and suggested that greater efforts were needed to encourage PA among Americans (11). Currently, a large discrepancy exists in the PA levels of US adults depending upon whether a subjective or objective measurement method is employed (12-13). In recognition of this disparity, the PAGA committee report emphasized the need for a better understanding of these measurement tools. Furthermore, the advisory committee identified a lack of knowledge regarding how objective PA measurements relate to a variety of health outcomes, and stated that such knowledge was “…needed before such measurements can be used to inform future physical activity recommendations and policy statements.” (11). Indeed, all PA research, including epidemiological, health-related, and
intervention-based, hinges upon the ability to measure field-based PA accurately. However, a lack of understanding currently exists regarding how subjective and objective PA relate to each other and how these differences affect the relationship between PA and health.

Habitual PA levels are inherently difficult to measure because of the need to measure long-term patterns which are often labile in nature. Currently, a wide range of assessment tools exist for measuring habitual PA including self-report questionnaires, direct observation techniques, and objective tools such as pedometers, accelerometers, heart-rate monitors, and multi-sensor devices. Each of these measures has advantages and disadvantages. Therefore, choosing the best tool for a particular research purpose depends upon several study factors such as the design, setting, sample size, budget, and demographic characteristics of the participants.

Generally, objective measures of PA are considered more valid than subjective measures, though the cost and inconvenience of these tools often excludes their use in large-scale studies. Historically, most PA epidemiology research has relied on self-report techniques because they are convenient, non-invasive, and relatively inexpensive. However, self-reported techniques are prone to measurement error from issues such as misinterpretation of questions, inability to recall, and social desirability (14-17). Though these issues cannot be eliminated, a greater understanding of the limitations of self-report tools would allow researchers to more accurately interpret resultant PA.

Currently, the proportion of U.S. adults meeting the new PAGA has only been assessed in one research study (18), which relied on a self-report measure. To date, only one study has examined previous national guidelines for PA using an objective, accelerometry-based measure (13). In addition, no studies are currently available which have compared the
PA levels of Americans measured from both self-report and accelerometer. Doing so would improve current knowledge of how physically active Americans are in regards to the PAGA, and would help facilitate a greater understanding of the relationship between PA levels when measured by self-report and accelerometer techniques.

**Dissertation Organization**

The overall purpose of this dissertation was to evaluate physical activity assessment issues and assumptions in the nationally representative National Health and Nutrition Examination Survey (NHANES). The NHANES data provides nationally representative data using both self-report and accelerometers so a fundamental goal was to understand measurement agreement between subjective and objective measures of activity. The NHANES incorporates both self-report and accelerometer PA measures for each adult subject, making it an ideal source for obtaining direct comparisons between the two measures. Study one of the proposed research assessed the proportion of the US adult population that achieved the 2008 PAGA when measured with a self-report instrument and an accelerometry-based activity monitor.

Though accelerometers provide an objective measure, there are inherent limitations that preclude them from being used as a criterion measure for PA. Specifically, accelerometers measure only locomotor movements, and cannot detect changes in grade or load. Furthermore, the accelerometer data requires a series of subjective processing techniques, which may introduce error into the measure. The magnitude of this potential for error has been demonstrated by the large differences in resultant PA that can be obtained from the same data (19-20). Though significant literature has been devoted to the calibration and validation of these devices, additional work is needed to clarify the effects of these
processing decisions and to help minimize potential error. Specifically, little has been done to establish the influence of wear-time compliance decisions on accelerometer outcomes. Therefore, the second study of the dissertation assessed the effects of accelerometer compliance processing on resulting physical activity levels in the US adult population, and determined the relationship between these PA outcomes and adiposity among US adults. By comparing the potential range in accelerometer PA to a known correlated variable, it was possible to provide insight into which accelerometer results were most highly correlated with the measure of interest, and potentially most representative of true PA levels. Ultimately, this study provided recommendations regarding accelerometer data processing, which if utilized, will improve the comparability of accelerometer study results in the future.

As documented in the PAGA, the link between self-reported PA and health-related outcomes has been well established (11). However, the available literature regarding the link between objective PA and health is sparse. Furthermore, no studies have assessed the relationship between health risks and PA assessed both subjectively and objectively. In doing so, the relationship that these assessment tools have on health outcomes can be compared to help differentiate which technique more accurately quantifies PA. Hence, the purpose of the third study of this dissertation was to assess the relationship between meeting the PAGA, when measured by self-report and accelerometry, with coronary heart disease (CHD) risk, the metabolic syndrome, and its individual risk factors among US adults. A secondary purpose of this study was to examine whether the relationship between objectively measured PA and CHD risk was affected by whether the activity was accumulated in sustained bouts of 10-min or more. This research provides new and important knowledge regarding self-reported and accelerometry-based PA assessment techniques. In addition, this
is the first study to assess the relationship between objectively measured PA and CHD risk among a representative sample of US adults. Therefore, this study also provides valuable insight into the relationship between objective PA and important health factors, and provides evidence regarding the benefits that achieving the PAGA can provide for the cardiovascular health of Americans.

References


CHAPTER 1

COMPARISON OF SELF-REPORT AND OBJECTIVE PHYSICAL ACTIVITY MEASURES IN THE NHANES: AN EXTENDED REVIEW OF THE LITERATURE

This research will examine physical activity assessment issues in the NHANES surveillance system. The literature review will provide background information and research summaries to guide the development of this work. The first section will briefly review research on the health benefits of physical activity and provide a summary of the recently established physical activity guidelines. The guidelines serve as the basis for public health surveillance so the second section will review current physical activity surveillance tools and provide an overview of the NHANES project. The final section will review physical activity assessment issues and describe the advantages and disadvantages of the different measurement tools. Special emphasis will be placed on accelerometer and self-report instruments since these will be the focus of the proposed research. The separate sections on these two techniques will review the available literature and provide an empirical rationale for the proposed comparisons and studies to be conducted in this research.

Physical Activity and Health

Being physically active is one of the most important ways people can improve their health. According to the 2008 Physical Activity Guidelines for Americans, there is strong evidence to support an inverse association between physical activity (PA) and several diseases and health problems including coronary heart disease, stroke, type 2 diabetes, osteoporosis, depression, some cancers, and all-cause mortality (1). Of particular interest is the inverse association between PA and cardiovascular disease (CVD), the number one killer in the US (2). In short, numerous health benefits have been linked with PA among a wide-
range of populations including both youth and adults, males and females, and across ethnicities. In addition, these findings have been shown using several different types and indicators of physical activity including aerobic fitness, structured exercise, and free-living activity performed during work, home, or leisure-time.

Many of the early studies examining the health benefits of PA have used aerobic fitness as a proxy measure for PA behavior (3). Physical fitness is typically assessed by maximal or submaximal exercise testing, which makes it a useful indicator of physical activity since it is relatively objective, accurate, and easy to measure. However, it is important that physical fitness not be confused with physical activity since fitness is also influenced by several other factors including age, sex, health status, and genetics (4). A review by Blair, et al. compared the health impact of fitness and activity on all-cause mortality (5). Each of the nine fitness-based studies included in the review found at least a 50% lower mortality rate among those in the highest fitness group compared to those in the lowest fitness group, with some showing a three- to four-fold difference in risk. Most of the 49 physical activity studies reviewed also showed an inverse dose-response relationship between PA and all-cause mortality, though the results were more variable. When comparing the two measures, the relationship between fitness and mortality was stronger and more consistent than the PA and mortality relationship. However, the authors concluded that this was likely due to the fact that fitness was objectively, and therefore, more accurately measured than the self-reported PA levels.

When examining the health effects of physical activity, researchers have typically used self-report PA tools due to their convenience and low cost, features that are especially important in epidemiological studies employing large sample sizes. A review conducted by
Lee et al. examined the relation between PA and all-cause mortality, and specifically assessed the role of volume and intensity on this relationship (6). Of the 38 PA papers reviewed, 26 assessed leisure-time PA, three assessed occupational PA, and nine assessed both leisure-time and occupational PA. The authors concluded that a dose-response trend was evident between the volume of PA (usually represented by energy expenditure) and all-cause mortality. This relationship was clear among both men and women, and in middle-aged and older adults. When examining the intensity of PA, there was a trend towards vigorous intensity activity being more beneficial than less-vigorous PA, though there were not enough studies to confirm this trend. However, the authors did suggest that it is logical to assume that higher intensities of activity will lead to a greater volume of PA if performed for a similar duration.

A review examining the PA and CVD relationship showed similar results (7). In short, the authors concluded that PA was negatively associated with CVD in a dose-response fashion. The review also separately examined coronary heart disease (CHD) and stroke, the primary manifestations of CVD. Results showed strong support for an inverse relationship between PA and CHD, though the results between PA and stroke were mixed. Thus, it appears that one of the primary ways PA reduces risk of CVD, and all-cause mortality, is through its effect on CHD. These findings have been confirmed in both middle-aged adults (8, 9) and older adults as well (10).

**Physical Activity Guidelines**

In recent decades the abundance of research documenting the health benefits of PA (and the detrimental effects of physical inactivity) has led health promotion agencies to recommend habitual PA as part of a healthy lifestyle. In 1995, the Centers for Disease
Control (CDC) and the American College of Sports Medicine (ACSM) issued the following PA recommendation to the public: “Every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week” (11). Since then, other PA guidelines have been issued with focuses on promoting energy balance as well as general health (12, 13). Recently, the initial CDC/ACSM recommendations were modified in order to adapt to progressions in the relevant literature. This update, published in 2007, established new aerobic PA guidelines for healthy adults (ages 18-65) which included a minimum of 30 min of moderate activity 5 d/wk, 20 min of vigorous activity 3 d/wk, or a combination of the two (14). This updated recommendation emphasized the added benefits associated with vigorous PA and provided clarification for how to distinguish moderate and vigorous intensities.

In 2008, the U.S. Department of Health and Human Services issued the Physical Activity Guidelines for Americans (PAGA) in order to provide guidance for PA to health professionals, policy makers, and the public (15). Similar to previous guidelines, the PAGA were developed by a committee of experts in the field who based their report on the available evidence regarding PA and health (16). Though the PAGA provides aerobic and strength training recommendations for children and adolescents, adults, and older adults, the current review will focus on the aerobic PA guidelines for adults. To obtain significant health benefits the PAGA recommends that adults obtain at least 150 min/wk of moderate-intensity aerobic activity, 75 min/wk of vigorous-intensity PA, or a combination of moderate and vigorous PA. Though similar to the 2007 ACSM/AHA guidelines, the PAGA gives adults more flexibility to accumulate weekly PA in various ways as long as it is performed in at least 10-min intervals. In addition, the PAGA increased the vigorous PA guideline from 60
min/wk to 75 min/wk. To understand why the guideline for vigorous activity was changed it is important to recognize how the advisory committee established the min/wk values.

When developing the PAGA, one of the key conclusions of the review committee was that the health benefits that result from PA are based, primarily, on the total energy expenditure (EE) during these activities. The committee also found that the amount of EE necessary to achieve many of the health benefits was in the range of 500-1000 MET-min/wk. Thus, the current PAGA guidelines were adapted from this MET-min estimate in order to simplify the recommendation for the general public. Using 3 METs as the threshold for moderate activity and 6 METs and above for vigorous, the 500 MET-min per week minimum was adapted into a min/wk estimate for moderate or vigorous PA. After conversion, 500 MET-min per week represented 167 min/wk of moderate PA (500/3) and 83 min/wk of vigorous PA (500/6). To simplify the guidelines, these estimates were rounded to 150 min/wk and 75 min/wk of moderate and vigorous PA, respectively. Since the moderate PA threshold (3 METs) is half of the vigorous threshold (6 METs) the PAGA can be achieved with half as many minutes of vigorous PA as moderate PA (i.e., both will produce the same EE in MET-min).

Physical Activity Levels in U.S. Adults

Self-Reported Physical Activity Levels

Despite the numerous health benefits that can be achieved with habitual PA, more than half of Americans fall short of current recommendations (17). In addition, nearly a quarter of US adults are completely sedentary resulting in substantial and unnecessary increases in health risks to these populations (18). Accurate assessments of PA are needed in order to understand which demographics are at the greatest risk, and to evaluate the impact of
current health promotion efforts. Until recently, epidemiological evidence for PA levels has relied exclusively on self-report assessment tools. Such studies often report segments of PA based on why it was performed, such as for leisure, occupational, transportation, or household tasks.

Most epidemiological PA studies have examined leisure-time activity exclusively (6), though some have looked at activities from multiple lifestyle contexts (19). Researchers may favor leisure-time PA since it is the most modifiable form of activity for most adults. However, other forms of PA should also be considered, as they can have a positive effect on health (19) and can also influence leisure-time PA. For example, one study found that leisure-time walking made up only half of total walking for adults (20). Another study showed that half of adults who report no leisure-time PA also report an hour or more of hard PA at work (21). Thus, it is important that all forms of PA be considered when assessing total PA levels.

One of the primary methods for tracking PA levels among US adults is through the Behavioral Risk Factor Surveillance System (BRFSS) survey. The BRFSS uses a random-digit-dialed telephone survey designed to assess PA performed in bouts of at least 10-min outside of work (i.e., during household work, transportation, and leisure-time). Recent estimates from the BRFSS suggest that the prevalence of Americans who were regularly active increased from 43% in 2001 to 46.7% in 2005 (17). For this study regular PA was defined as meeting the 30 min/d on 5d/wk guideline. Another report based on part of the same dataset (2001-2003) showed similar trends in activity levels (45.3% in 2001 and 45.9% in 2003) (22).
To assess levels of physical inactivity outside of work, the BRFSS uses the classification of reporting no activity of 10-min or more of moderate or vigorous PA. According to this definition, the prevalence of lifestyle inactivity has remained relatively stable overall (16.0% in 2001 and 15.6% in 2003), with significant decreases in 14 states and territories, and significant increases in 5 states and territories (22).

Recently, one study assessed the prevalence of US adults who met the PAGA (150 min/wk) according to data from 2007 (23). To assess a combination of moderate and vigorous PA, the number of vigorous minutes was multiplied by two before being combined with moderate minutes. The authors found that 64.5% of adults achieved the PAGA (68.9% of men and 60.4% of women). When compared to the ACSM/AHA guidelines only 48.8% of Americans (50.7% of men and 47.0% of women) achieved the guidelines. The authors suggested two reasons why there was difference between the PA prevalence rates. First, the PAGA was easier to achieve because it did not have a daily frequency and duration requirement (i.e., 30 minutes of moderate activity, 5 days per week, or 20 minutes of vigorous activity, 3 days per week). In addition, the PAGA criteria allowed respondents to attain the guidelines through a combination of moderate and vigorous (multiplied by two) activity.

Objective Physical Activity Levels

In 2008, nationally representative data of objectively measured PA levels were released (24). Using accelerometer data from National Health and Nutrition Examination Survey (NHANES) 2003-2004, Troiano et al. (24) found PA trends with similarities to self-report data (i.e., males were more active than females, PA declined with age, etc.). However, actual PA levels were drastically different than had been previously reported. When
categorized according to the 2007 ACSM/AHA guidelines, results showed that less than 5% of adults obtained enough moderate or vigorous PA to reach the guideline. Total minutes of MVPA ranged from 23.6 min/d for young adults (aged 20-29) to 5.4 min/d for those in the oldest category (aged 70+). Furthermore, when considered in bouts of at least 10 min, PA levels ranged from a mere 7.4 min/d to 2.2 min/d from the youngest to oldest age group, respectively.

Using the same accelerometer data (NHANES 2003-2004), Metzger et al. categorized US adults by their daily activity patterns using latent class analysis (25). Results showed 5 classes of activity patterns, with 34% of the adult population falling into the least active class (5.4 min/d MVPA). The second-lowest PA class obtained an average of 21.0 min/d MVPA and made up 45% of adults. Thus, the majority of adults (79%) were classified into categories that were well-below recommended PA levels. Even fewer adults were found to be active when the classifications were developed from data showing only PA occurring in 10-min bouts.

The divergent results observed for self-report and accelerometer-based assessments raises concerns regarding the validity of one, or potentially both, of these tools. According to both PA assessments, the US adult population has substantial potential for improved health through improvements in currently inadequate PA levels. Indeed, the need for additional PA promotion efforts is especially apparent when considering the accelerometer-based results. However, for appropriate PA promotional efforts and public policies to be made, a clearer understanding of true PA levels in the US is needed. Thus, further investigation is warranted in order to identify reasons for these divergent PA findings, and if possible, to improve the accuracy of these tools.
Physical Activity Surveillance Tools

As indicated previously, current activity levels in the US vary widely depending upon the PA assessment tools used. Specifically, PA results were substantially higher when using self-report measures when compared to accelerometer measures. In order to determine what factors may lead to these discrepancies it is important to understand how these instruments work and the potential sources of error inherent to each.

Self-Report Physical Activity

Self-report tools are the most commonly used method for assessing PA, especially in large-scale research, due to acceptability, cost, convenience, and low interference with physical activity behavior (26, 27). In addition, self-report PA measures provide the benefit of being able to capture the frequency, duration, intensity and type of PA reported. Often, the self-reported activities are categorized into the domain in which they are performed (i.e., leisure-time, occupational, domestic, and transportation), allowing researchers to characterize how PA is accumulated throughout the day.

Typically, self-reported PA is measured using a series of questions presented in the form of a questionnaire or interview. Such questionnaires require respondents to report recent or typical PA behaviors, usually over a set period of time. Most self-report tools use either a time-based or an activity-based recall strategy. Time-based measures help facilitate recall of past PA by dividing the day into separate periods, after which activities performed during each period are reported. Activity-based recalls involve recalling the specific types of PA that are typically performed, and then estimating the frequency and duration of each activity over a given period of time. Both time-based and activity-based instruments usually also involve reporting the intensity (e.g., moderate, vigorous) that corresponds to each reported PA.
Though self-report tools offer some advantages over other measures, they also have several limitations which may introduce bias into the estimate. Discrepancies between self-reported and actual PA may result from some respondents who are unable to accurately recall all PA performed over a given period, which could lead to underestimation. Conversely, some respondents may tend to overestimate their PA, since higher activity levels are socially desirable (28). For example, one study examining this link found that social desirability was the strongest predictor of physical activity frequency in 423 adults (18-50 yrs old) (29). However, other research has shown that social desirability only accounted for 1-3% of the variance in self-reported PA levels (r = 0.11-0.17) (30).

Misinterpretation of survey questions may also lead to biased results. According to Baranowski et al, recalling physical activity is a complex cognitive task, which requires respondents to understand ambiguous terms such as “physical activity”, “leisure-time”, and “moderate-intensity” (31). Unfortunately, such terms are often interpreted differently depending on education, culture, experience, or other personal factors.

Another limitation of PA surveys is that they often fail to capture all domains of activity (28). Leisure-time activity has been most commonly promoted form of PA, so a number of have focused exclusively on this domain. The increased emphasis on lifestyle activity has led to the development of instruments with an emphasis on total PA levels. Instruments with this focus have items that attempt to capture activity in different domains. For example, the BRFSS captured only leisure-time activity from 1984-2000 (32). Starting in 2001, the BRFSS incorporated a new set of questions which assessed PA from leisure-time, domestic, and transportation. Other national surveys also capture these three domains
including the Youth Risk Behavior Survey (YRBS) and the National Health and Nutrition Examination Survey (NHANES).

To examine the accuracy of self-report questionnaires, Neilson et al. reviewed EE estimates from 20 studies with 23 separate comparisons between PA surveys and doubly-labeled water (DLW) (33). Eleven of the questionnaires covered occupational, household, and leisure time activities, while others covered 2 or fewer domains. The surveys also ranged from recalling activities during short durations (e.g., past week) to long durations (e.g., past year) and also varied regarding whether typical or actual PA was reported. The percentage difference in mean values of EE ranged from \( \leq 10\% \) to 113\% and from \(-10\) kcal/d to 952 kcal/d. Further, correlation coefficients between self-reported PA and DLW ranged from 0.05 to 0.83, with 5 surveys exhibiting correlations above 0.60. When examining whether self-report measures produced negative differences (over reporting) or positive differences (underreporting), the data were split relatively equally. The authors concluded that differences between the criterion EE and estimated EE may have been due, in part, to the inability to capture EE associated with low-intensity (lifestyle) activities. Another source of error is due to the poor temporal matching between the surveys and the DLW (e.g., past year vs. past 2 weeks). In addition, the authors suggested that MET values may have been inaccurately assigned to some reported activities, since corresponding MET values are based on average intensities which do not apply to everyone (34).

**Accelerometer Physical Activity**

Accelerometers are devices that detect accelerations produced by the body (35). Piezoelectric transmitters inside the monitors detect the accelerative forces, and produce an electrical signal that is filtered and then converted into a unit of movement (i.e., counts) (36).
These counts are summed over a specific time interval (i.e., epoch) and then stored in the memory as an indicator of movement intensity over the given time period. This process is then repeated throughout the duration of a given wear time. Resulting data can be processed to produce the frequency, intensity and duration of PA.

Accelerometers are useful for PA assessment because they are small, noninvasive, and provide an objective measure of movement (35). These advantages have allowed accelerometers to become widely used and accepted as the preferred method for capturing objective PA. However, these activity monitors also have some limitations. Accelerometers are typically worn on the hip which allows them to effectively monitor locomotor movements, but makes them less accurate for activities which produce little vertical oscillation such as cycling or upper-body activities. In addition, activity monitors cannot account for movements which require extra effort such as walking uphill or carrying loads which can result in biased estimates of EE or time spent in PA.

In 2003, the NHANES incorporated the use of accelerometers in order to objectively measure physical activity in the US population. Researchers from the NHANES stated that an objective PA measure was needed due to the importance of PA for health, and because accurate reports of PA levels in large, free-living populations were not currently available due to the limitations of self-reported PA (37).

The monitor used in the NHANES research was the Actigraph (formerly CSA/MTI) model 7164 (Actigraph LLC; Ft. Walton Beach, FL) accelerometer. This monitor was chosen because of its “…long record of accomplishment in clinical and community-based physical activity studies” (37). In addition, the Actigraph has a step-counting feature which may be useful to some researchers utilizing the NHANES data. The Actigraph is the most widely
used accelerometer for field-based research (35) and has been well-validated, especially among adults (38-42). The Actigraph is a uniaxial accelerometer, which means that it measures acceleration in one dimension (vertical). The monitor also filters out accelerations outside of the potential range for human movement, such as riding in a vehicle (43).

Indeed, the incorporation of accelerometers in the NHANES was a large step forward in the field of PA research. However, a major challenge that remains for researchers utilizing accelerometers is determining the relationship between the raw data and actual physical activity levels (i.e., calibration) (43). Specifically, these challenges include determining whether monitors were adequately worn (i.e., participant compliance), choosing how to handle non-wear (i.e., missing data), and deciding how to manipulate and analyze the data to produce PA outcomes (44). Since some of these calibration options are monitor-specific, the following description of these issues will focus on the Actigraph monitor.

Missing data can have a negative impact on all types of research, potentially leading to selection bias. In accelerometer research, missing data can occur as a result of refusal to participate, but also from subjects who fail to wear the monitor according to the study protocol. Accelerometer wear is influenced by waking hours, forgetfulness, and activities during which the monitor cannot be worn (e.g., swimming, bathing, competitive sports). Fortunately, researchers have the ability to monitor non-wear by assessing periods in which the data display no acceleration (i.e., epochs with 0 counts). However, determining compliance criteria based on when and how much data are missing is difficult, and can have a significant impact on PA results (45). For example, including monitoring days in which the accelerometer was worn for only a few hours may lead to underestimating PA levels. Conversely, excluding monitoring days could lead to an overestimation of PA.
**Accelerometer Data Processing**

One decision that must be made when processing accelerometer data is how to define a “day” (i.e., wake-time). This can be done by requiring participants to have a set number of hours of monitor wear (e.g., 12 hours) or by setting a “beginning” and “ending” time during which compliance will be monitored (e.g., 9 am to 9 pm). When using the latter method, the set times are only used to restrict when compliance is checked, which means PA performed outside of these times is still counted. Setting a beginning and ending to each day provides the benefit of ensuring a similar structure for each day, such that the monitor cannot be forgotten in the morning and then worn later to obtain an adequate wear time. Therefore, this method may be preferable for study samples that have similar schedules (e.g., school-attending children).

However, since wake and sleep times often vary between individuals, and even within individuals (e.g., weekday vs. weekend), the “set number of hours” approach has been recommended (45, 46). The number of hours used to define a day has varied considerably in previous research, though 8 hours (47) and 10 hours (48-50) have been most commonly used.

In addition to daily wear time, decisions must also be made regarding the allowance for monitor removal throughout the day (i.e., partial non-compliance). Even while sedentary, accelerometers will still record some movement. Thus, sustained periods of 0-counts indicate non-wear. Activity logs are necessary in order to determine whether the removal was justified (e.g., swimming) or non-compliant (e.g., forgetting). However, in large studies such as the NHANES, manual comparisons between activity logs and monitor data are not feasible. As an alternative, an established amount of time (e.g., 30 min) is often established such that sustained 0-counts which exceed that time limit are flagged as partial non-
compliance. These flagged periods can then be totaled for each day and used to establish day-level compliance. Previous studies have checked for sustained 0-counts ranging from 10 min to 60 min in length \( (45,46,48) \)

Once wear-time criteria has been set, the data can be screened to assess levels of participant compliance. Typically, compliance is first assessed for each individual day (day-level compliance). Flagged periods of missing data are removed from daily wear-time totals after which each day’s wear-time is compared to the established standard (e.g., 10 hours). If the monitor is not worn sufficiently on a given day then that day will be deemed non-compliant and excluded from analyses. Using this process, the number of compliant days can then be calculated for each participant.

Participant-level compliance can be established by setting a minimum number of compliant days necessary for a subject to be included in the analyses. This step is necessary because the degree to which the data reflect actual physical activity levels is dependent upon the number of days it is measured \( (51) \). For example, results from a subject with only one compliant day of monitor wear will be less likely to represent that person’s actual PA level when compared to results from subjects with seven compliant days. Previous research has indicated that, in adults, four to seven days of monitor wear were necessary to obtain reliable data (intraclass correlation \( = 0.8 \)) \( (51) \). Typically, protocols in which monitors are worn for seven days are recommended, since this practice allows both weekday and weekend periods to be measured, and provides a balance between participant burden and reliable estimates \( (52) \).

In addition, longer protocols, such as 7-days, allow for some data loss due to non-compliance, while still being able to maintain reliable measures. However, the number of
days needed to be included in the final analyses has varied in previous research. When making this decision, it should be kept in mind that choosing a higher threshold for compliant days will result in data that more closely reflect the actual activity levels of the sample, but in a lower number of subjects included in the analyses. Of course, requiring a lower number of compliant days will have the opposite effect. Thus, consideration must be taken as to how to optimize the balance between measurement error and selection bias.

In the past, study requirements have ranged from a minimum of three (50) to seven (51) compliant days, with most falling somewhere in between (24, 47, 53). Minimums are often set for weekend days as well. For example, Cleland et al. (47) required a minimum of 4 compliant days including 1 weekend day, and Eslinger et al. (53) required 5 days including 1 weekend day. In previous NHANES accelerometer research, Troiano et al. used a minimum of 4 valid days to be included in analyses (24). Therefore, the current analyses will use this standard as a reference point to which other criteria will be compared.

Once the compliance has been checked and non-compliant days and subjects removed, the accelerometer counts can be processed to obtain PA outcomes. These measures can include time spent in specific PA intensities (either total time or time spent in bouts), total physical activity (total counts per day), or average physical activity intensity (average counts per minute). To calculate time spent in PA intensities, monitor-dependent calibration equations have been developed which provide cut-points used to divide accelerometer counts into these intensity categories. Other calibration equations have also been developed which allow accelerometer counts to be converted into MET values, and ultimately, EE (54).

Since the current work focuses on PA guidelines using the NHANES, the primary literature of interest includes studies which provide moderate and vigorous cut-points for
adults wearing the Actigraph. To develop these cut-points, studies measured activity counts during several walking and running speeds (55-59) or while performing a series of free-living activities (60, 61). Unfortunately, there are substantial differences between published cut-points which leads to significant variability in PA estimates. For the Actigraph, adult studies have developed cut-points which range from 191 (60) to 3285 (56) for moderate PA, and from 4945 (61) to 7526 (60) for vigorous PA.

When comparing these cut-points, it appears that the locomotor-based thresholds are able to estimate EE dynamic activities well, though they tend to underestimate EE from free-living activities (54). Conversely, cut-points developed from free-living activities work best for combinations of dynamic and static activities, but tend to overestimate activities which are exclusively locomotor in nature. Currently, there is not a single set of intensity thresholds for the Actigraph that is widely accepted as the standard. However, some studies have used a combination of currently published cut-points, which may minimize the potential for over- or underestimation of PA when compared to a single calibration study (24, 25).

Though several studies have been published regarding the challenges of processing accelerometer data (35), there is currently no standardized approach available for decisions such as setting compliance criteria and choosing intensity cut-points. However, this literature review helps to show the potential range in decisions that previous researchers have made, as well as the most common choices. A better understanding of how these criteria affect study outcomes is needed to help accelerometer researchers make improved decisions regarding study design, and to improve their comprehension of potential limitations. Therefore, the current research will compare the effects of these accelerometer processing criteria on resultant PA levels among U.S. adults.
Physical Activity in the NHANES

Of particular interest to the current research is the NHANES, which provides health data for Americans through a combination of personal interviews and physical examinations. Though smaller than other national surveys such as the BRFSS, the data collection techniques used in the NHANES provides much more specialized information than other US surveys including self-reported and objective physical activity data, and detailed measures of anthropometry, adiposity, and cardiovascular disease risk factors (62).

Self-reported Physical Activity in the NHANES

The self-report PA component of NHANES was collected as part of a household interview. The PA questions were first used in 1999, and included three domains (transportation, domestic, and leisure-time) for adults. Each domain was assessed through a series of close-ended questions that relied on participants recalling activities performed during the past 30 days (63).

For the transportation domain, participants recalled all walking and bicycling that was performed to transport them to or from work, school, or errands. The average frequency and duration of these activities was also reported, though the average intensity was not. Instead, NHANES suggested an estimated intensity (4.0 METS) for all transportation activities, based on the Compendium of Physical Activities reference and its authors (64).

Household PA was assessed similarly. Participants were asked if they performed tasks in or around their home which lasted at least 10 minutes and required at least moderate effort (light sweating or slight to moderate increase in heart rate or breathing) (63). The frequency and duration of these activities were reported, and the intensity was estimated to be 4.5 METS.
For leisure PA, respondents who reported doing leisure-activities within the past 30 days were presented with a list of 48 potential activities including an “other” category (65). After selecting an activity, participants provided the average frequency and duration for the activity during the past 30 days, and reported whether the activity was performed at a moderate or vigorous intensity. This was then repeated for each leisure activity reported. The NHANES provided average MET values which can then be assigned to each activity based on its type and the reported intensity (moderate or vigorous) (64).

The NHANES self-report PA has been widely utilized since its creation in 1971 (NHANES I). One use of these data has been to estimate PA levels by various demographic groups (66-71). However, due to the breadth and detail of information collected during the NHANES, the self-report PA data have been more extensively employed in correlational research (i.e., comparing PA to health outcomes). Specifically, associations have been compared between activity levels and mortality (72), cardiovascular risk factors (73-74) including obesity (75-77), cancer (78, 79), diabetes (80), psychosocial factors (81, 82), and other health concerns (83-87).

**Accelerometer Physical Activity in NHANES**

In 2003, an accelerometer protocol was incorporated into the NHANES, marking the first time population-based physical activity levels were assessed objectively in the United States (24). During the NHANES physical examination, each participant aged 6 and older was asked to wear the Actigraph accelerometer continuously for a 7-d period (88). Accelerometers were worn over the right hip on an elasticized belt, and afterwards mailed back to the NHANES research staff. Upon return, monitors were downloaded and the data were checked for errors. The monitor data were made available through the NHANES
website (89), though additional processing is necessary in order to interpret PA outcomes from the raw accelerometer results. As described previously, the data must be checked for non-compliant participants and then converted from raw accelerometer counts into a useful measure of PA such as EE or min/d of moderate and vigorous activity.

To date, objective PA from the NHANES has not been widely utilized in the literature. This is likely due to its recent inception into the NHANES, and because of the complexities associated with processing accelerometer data. Thus far, the NHANES accelerometer data have been primarily used to assess physical activity levels among the US population (24, 25), though correlate research has also started to emerge (90).

**Summary**

The current literature review provides a brief background regarding the health benefits of PA, and how this information was used to establish the Physical Activity Guidelines for Americans. The proposed research will draw upon the information in this review in order to assess current levels of PA in the U.S. according to these guidelines. This will be done using both self-report and accelerometer-based measures of PA from the NHANES. Doing so will help show the potential range in actual levels of adult PA, and will also provide a unique comparison between these assessment tools. The current review shows how these two measures of PA are assessed in the NHANES, and helps to explain the advantages and disadvantages of each. Having provided this background will facilitate the processing of the NHANES data, and will promote a greater understanding of how to interpret the findings from the proposed research.
References


CHAPTER 2

COMPARISON BETWEEN SELF-REPORTED AND OBJECTIVELY MEASURED PHYSICAL ACTIVITY LEVELS IN US ADULTS: COMPLIANCE WITH THE PHYSICAL ACTIVITY GUIDELINES FOR AMERICANS

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Introduction

Physical activity (PA) is one of the most important lifestyle behaviors people can perform to improve their health. The literature strongly supports an inverse, dose-response relationship between PA and several diseases and health problems including coronary heart disease, stroke, type 2 diabetes, osteoporosis, depression, some cancers, and all-cause mortality (1). Furthermore, many of these reduced risks have been demonstrated across ethnicities and age groups, including children and adolescents (2-5). Due to these numerous health benefits, substantial efforts have been made to promote PA in the U.S. population. From a government standpoint, these efforts range from social marketing campaigns run by the Centers for Disease Control and Prevention that encourage PA in youth (6), to nationwide PA goals established for Healthy People 2010 (HP2010) (7).

Recently, the U.S. Department of Health and Human Services also issued the Physical Activity Guidelines for Americans (PAGA), which updated the evidence regarding PA and health, and helped promote PA directly to the public and indirectly through health professionals and policy makers (8). Similar to previous guidelines, the PAGA were developed by a committee of experts who based their report on the available evidence regarding PA and health (9). The PAGA provides aerobic and strength training
recommendations for children and adolescents, adults, and older adults. The current research focuses on the aerobic PA guidelines for adults.

In 1995, the American College of Sports Medicine (ACSM) in conjunction with the Centers for Disease Control and Prevention (CDC) introduced physical activity guidelines designed to promote public health. These guidelines recommended that adults engage in at least 30 minutes of moderate-intensity PA on most days of the week (10). Then in 2007, the ACSM and the American Heart Association (AHA) developed new PA guidelines designed to update prior recommendations (11). The primary recommendation from the ACSM/AHA guidelines stated that adults should obtain either 30 min of moderate-intensity PA 5 d/wk, 20 min of vigorous-intensity PA 3 d/wk, or a combination of the two. Though similar to the 1995 guidelines, the 2007 aerobic guidelines clarified the frequency of moderate PA (5 d/wk) and identified vigorous PA as a potential supplement or substitute to moderate PA.

In 2008, the PAGA were introduced, which further modified previous PA guidelines. The PAGA recommended that adults obtain at least 150 min/wk of moderate-intensity PA, 75 min/wk of vigorous-intensity PA, or a combination of moderate and vigorous PA. In comparison to the 2007 ACSM/AHA guidelines, the PAGA give adults more flexibility to accumulate weekly PA in various ways as long as it is performed in at least 10-min intervals. In addition, the PAGA increased the vigorous PA guideline from 60 min/wk (20 min x 3 d/wk) to 75 min/wk. To understand why the guideline for vigorous activity was changed, it is important to recognize how the advisory committee established its aerobic PA recommendations.

When developing the PAGA, one of the key conclusions of the review committee was that the health benefits that result from PA are based, primarily, on the total energy
expenditure (EE) during these activities. The committee also found that the amount of EE necessary to achieve many of the health benefits was in the range of 500-1000 MET-min/wk. Thus, the current PAGA guidelines were adapted from this MET-min estimate in order to simplify the recommendation for the general public. Using 3 METs as the threshold for moderate PA and 6 METs as the threshold for vigorous PA, the 500 MET-min per week minimum was adapted into a min-based estimate for moderate and vigorous PA. After conversion, 500 MET-min per week represented 167 min/wk of moderate PA (500/3) and 83 min/wk of vigorous PA (500/6). To simplify the guidelines, these estimates were rounded to 150 min/wk and 75 min/wk of moderate and vigorous PA, respectively. Since the moderate PA threshold (3 METs) is half of the vigorous threshold (6 METs), the PAGA can be achieved with half as many minutes of vigorous PA as moderate PA (i.e., both will produce similar EE).

Conclusions from the PAGA advisory committee report confirmed the importance of PA for individuals of all ages, and suggested that greater efforts were needed to encourage PA among Americans. These findings emphasize the importance of being able to accurately track PA levels in order to identify high-risk populations and to assess the impact of current PA promotions. In short, all PA research, whether correlational, epidemiological, or promotional in nature, hinges upon the ability to measure field-based PA accurately.

Unfortunately, habitual PA levels are inherently difficult to measure because of the need to assess long-term patterns, which are often labile in nature. Currently, a wide range of assessment tools exist for measuring habitual PA including self-report questionnaires, direct observation techniques, and objective tools such as pedometers, accelerometers, heart-rate monitors, and multi-sensor devices. Each of these measures has advantages and
disadvantages (12). Therefore, choosing the best tool for a particular research purpose depends upon several study factors such as the design, setting, sample size, budget, and demographic characteristics of the participants (13,14).

Generally, objective measures of PA are considered more valid than subjective measures, though the cost and inconvenience of these tools often precludes their use in large-scale studies. Instead, the vast majority of PA epidemiology research relies on self-report techniques because they are convenient, non-invasive, and relatively inexpensive (15). However, self-reported techniques are prone to measurement error from issues such as inability to recall and social desirability (16,17). Though these issues cannot be eliminated, a greater understanding of the limitations of self-report tools would allow researchers to more accurately interpret resultant PA.

Currently, the proportion of U.S. adults meeting the new PAGA has only been assessed in one research study (18), which relied on a self-report measure. To date, only one study has examined previous national guidelines for PA using an objective, accelerometry-based measure (19). In addition, no studies are currently available which have compared the PA levels of Americans measured from both self-report and accelerometer. Doing so would improve current knowledge of how physically active Americans are in regards to the PAGA, and would help facilitate a greater understanding of the relationship between PA levels when measured by self-report and accelerometer techniques.

The purpose of the current study was to assess self-reported and objectively measured physical activity levels among US adults according to the Physical Activity Guidelines for Americans. The proportion of Americans meeting the PAGA were evaluated using three representations of the aerobic PA guideline: moderate plus vigorous physical activity
(MVPA), moderate plus two-times vigorous physical activity (M2VPA), and MET-minutes of physical activity (METPA). An ancillary objective of the study was to compare self-report and accelerometer PA outcomes, in order to gain insight into the relationship between these two assessment tools.

**Methods**

**Study Population**

Data for the current study were obtained from the National Health and Nutrition Examination Survey (NHANES) 2005-2006. The NHANES was conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (CDC) in order to monitor the health status of the US population. Data for the NHANES were collected year-round as an ongoing series of cross-sectional surveys. The survey used a multi-stage probability cluster sampling design, which provided nationally representative data, improved data collection feasibility, and allowed for the study of sub-populations.

All counties within the US served as the sampling frame for the NHANES design. For 2005-2006, fifteen single counties (or combinations of small counties) were selected throughout the country as the primary sampling units. Within these counties, clusters of households were selected, after which one or more persons within each household were recruited for participation. Oversampling of certain subpopulations was done to increase the reliability and accuracy of health estimates for these groups. In order to account for this oversampling design, NHANES provided weights for each respondent, which indicated the probability of being sampled. The use of these weights was necessary in order to make valid statistical inferences about the US population from the NHANES sample.
Data for NHANES 2005-2006 were collected by staff within selected households and in mobile examination centers (MEC). Household surveys included questions regarding demographic information and PA habits. Standardized medical examinations were conducted within the MEC usually 1-2 weeks after the household interviews and included anthropometric and adiposity measurements including height, weight, waist circumference, and skinfolds. In addition, PA monitors were distributed to participants during the MEC visit along with instructions regarding how the monitors were to be worn. All survey instruments, examinations, and instructions were available in English and Spanish languages.

A total of 12,761 children and adults were selected for the study sample in NHANES 2005–2006. Of those selected 10,122 were interviewed and 9643 participated in the MEC exam and agreed to wear the physical activity monitor for the 7-d period. The current study sample was limited to adults, aged 20 years or older at the time of NHANES 2005-2006. All ethnicities were included in analyses involving the total sample, but when examining individual ethnicities, the sample size of these sub-groups limited analyses to non-Hispanic white (white), non-Hispanic black (black) and Mexican American populations. The NCHS ethics review board approved survey and examination protocols and all participants signed an informed consent document.

Measures

Self-Report Physical Activity

Self-reported PA levels were assessed during the household interview and included a series of questions that required participants to recall behaviors during the past 30 days. Questions focused on PA performed during transportation activities, household tasks, and leisure-time pursuits. Transportation PA was calculated from questions that assessed the
frequency and duration of walking or biking to and from work, school, and errands. Similarly, household PA was determined from questions that required participants to list the frequency and duration of household tasks that required at least moderate effort (e.g., mowing the lawn or heavy cleaning). Estimated intensity levels were assigned to all reported transportation activities (4.0 METS) and household activities (4.5 METS) based on the Compendium of Physical Activities and communication with the Compendium’s authors (20).

For leisure-time PA, respondents were asked to report the moderate and vigorous leisure activities they performed during the past 30 days. A list was also provided with examples of activities. For each PA specified, participants were asked how many times they performed that activity during the past 30 days, how long the activity was performed on average, and the level of exertion that best corresponded to the activity (moderate or vigorous). Moderate activities were defined as those that caused light sweating or a slight to moderate increase in breathing or heart rate, whereas vigorous activities included those that caused heavy sweating or a large increase in breathing or heart rate. Two MET scores (one for moderate and one for vigorous) were produced for all reported activities (20). One of the two developed MET scores was assigned to each reported activity based on whether the respondent reported doing the activity at a moderate or vigorous intensity.

Accelerometer Physical Activity

All ambulatory adults were asked to wear a physical activity monitor for 7 consecutive days. The monitor chosen for the NHANES 2005-2006 was the Actigraph (Actigraph, LLC; Ft. Walton Beach, FL) model 7164 accelerometer due to its widespread use in clinical and community-based physical activity studies. The Actigraph is a lightweight
uniaxial monitor that records the frequency and intensity of accelerations in the vertical plane. Monitors were distributed to participants during the MEC examination with instructions regarding how and when it was to be worn. Specifically, monitors were placed on elastic, custom-fitted belts and worn over the right hip throughout the 7-day period. Participants were instructed to begin wearing the monitor the day after the MEC examination and to only remove the device during sleep and water-based activities (e.g., bathing and swimming).

The monitors were programmed to record data in 1-minute intervals (epochs) beginning at 12:01 a.m. the day after the health examination. Subjects were provided with postage-paid padded envelopes in order to return the monitors after the 7-day period. Upon return, monitors were downloaded and checked to determine whether they were still correctly calibrated using software provided by the manufacturer. Intensity files were also reviewed for outliers and unreasonable values based on published literature and expert judgment.

**Demographic and Anthropometric Measures**

Participants’ PA levels were categorized by gender, age, race/ethnicity, and body mass index (BMI) in order to allow for comparisons among these groups. Age was categorized into 6 groups: 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, and 70 years or older. Race/ethnicity was self-reported and for the current study included 3 groups: non-Hispanic white, non-Hispanic black, and Mexican American. Trained health technicians measured height and weight using a calibrated stadiometer and digital scale, respectively. Body mass index (calculated by dividing subjects’ weight in kilograms by their height in meters squared) was provided in the NHANES data set. Participants were categorized by weight status as either normal weight (BMI < 25), overweight (BMI 25 to
29.9), class I obese (BMI 30 to 34.9), or class II obese and above (BMI ≥ 35) to allow for PA comparisons between these groups.

**Data Processing**

**Self-Report Physical Activity**

The self-report data were processed using three different methods to evaluate the impact of these approaches on resultant PA. The first approach involved computing total time spent in MVPA. Minutes of MVPA were calculated for each reported activity by multiplying the average duration of the activity by its frequency, after which each of the activities were summed to produce the total number of MVPA minutes over the past 30 days. These values were then converted into weekly MVPA to allow for comparison with the 2008 PAGA. Participants were categorized into 3 activity levels based on time spent in MVPA: no reported MVPA (0 min/wk), insufficient MVPA to meet the guidelines (1-150 min/wk), and sufficient MVPA to meet the guidelines (≥150 min/wk).

The guidelines can be achieved with 150 min/wk of moderate PA, 75 min/wk of vigorous PA, or a combination of the two. Therefore, the second approach used the weighting procedure recommended in the appendix of the PAGA (21) in which 1 minute of vigorous PA is equivalent to 2 minutes of moderate PA. Thus, the M2VPA method gives double credit for vigorous PA in order to allow for a similar metric (i.e., energy expended in PA) when combining the moderate and vigorous intensities. Similar to the MVPA calculations, participants were also sorted into 3 categories based on M2VPA levels: no reported M2VPA (0 min/wk), insufficient M2VPA to meet the guidelines (1-150 min/wk), and sufficient M2VPA to meet the guidelines (≥150 min/wk).
In the third approach, PA levels were calculated using MET-minutes. Total MET-minutes of PA were calculated by multiplying the weekly PA volume (duration x frequency) of each activity by its corresponding MET value (METPA). For example, if a participant reported 60 min/wk of vigorous basketball during the week, the corresponding MET score for vigorous basketball (i.e., 8.0 METs) would be multiplied by the 60-minute duration for a total of 480 MET-minutes per week. Participants were categorized into one of the following three guideline-based activity levels according to their total weekly METPA: No reported METPA (0 MET-min/wk), insufficient METPA to meet the guidelines (1-499 MET-min/wk), and sufficient METPA to meet the guidelines (≥500 MET-min/wk).

**Accelerometer Physical Activity**

Accelerometer-based PA was processed similarly to the self-reported PA to provide direct comparisons between the three methods of evaluating the PAGA (i.e., MVPA, M2VPA, and METPA). However, the accelerometer data required additional processing procedures to check subject compliance and to determine the PA intensities. Accelerometer processing was conducted using processing programs made publically available by the National Cancer Institute (22), but with some modifications in order to create the needed outcome measures.

Compliance with the monitor-wearing protocol was assessed on a daily basis for each participant. Specifically, participants were considered compliant if they wore the monitor for at least 10 hrs/d on at least 4 out of the 7 days. Removal of accelerometers was detected by assessing any period of at least 60 min during which no data were recorded (0-counts). Using these criteria, only participants deemed compliant were included in the current analyses.
In order to determine minutes of moderate and vigorous PA from accelerometer counts, intensity cut-points were applied to the data. The current research utilized cut points that were established using a weighted average of the thresholds developed for adults wearing the Actigraph, as has been done in previous research (19, 23).

The first accelerometer outcome measure reflected the total number of minutes of MVPA performed in 10-min bouts throughout the week (MVPA). Total minutes of MVPA were summed from all compliant days for each participant with at least 4 compliant days. Weekly activity levels were then calculated based on the number of compliant days each participant accumulated. For example, if a participant had 4 valid days and accumulated 60 minutes of moderate activity during that time, a total of 105 min/wk (60min * 7d / 4d = 105min) of moderate PA would be estimated for the 7-day period. The second accelerometer PA estimate, M2VPA, was computed in a manner similar to accelerometer MVPA, except that minutes of vigorous PA were doubled before being combined with moderate PA. For both MVPA and M2VPA, participants were categorized into the following 3 PA levels based on guideline adherence: 0 min/wk, 1-149 min/wk, and 150+ min/wk.

The third accelerometer outcome measure was computed to create a measure that would parallel the self-report MET-min variable. Accelerometer METPA was calculated by converting accelerometer counts into MET-min using a published equation developed for the Actigraph (24). In order to screen out MET-min that were accumulated at lower PA intensities, accelerometer counts below the threshold for 3 METs according to the equation (<1964 counts/min) were not included in the MET-min total. Adherence to the PAGA was assessed for accelerometer METPA using the following 3 categories: 0 MET-min/wk, 1-499 MET-min/wk, and 500+ MET-min/wk.
The PAGA recommends that aerobic activity be performed in bouts of at least 10 min or more. For self-report PA, participants were instructed to only report activities that lasted at least 10 min. Therefore, all self-reported activities can, in theory, be interpreted as PA performed in sustained bouts. For accelerometer PA, both the MVPA and M2VPA methods were also calculated using only PA performed in 10-min bouts. In order to account for occasional stoppages in sustained PA sessions, at least 8 out of 10 consecutive minutes at or above moderate intensity were required to be included in the total. For METPA, total MET-min was used to assess guideline compliance.

Data Analysis

All data processing and statistical analyses were performed using SAS version 9.1. Analyses used sampling weights that were calculated based on the final sample. These sample weights are necessary to account for unequal probabilities of selection, nonresponse, noncompliance, and a poststratification adjustment to the estimated US population. Descriptive analyses included adjusted frequencies and means conducted for each gender, age group, race/ethnic group, weight status group, and for each PA assessment method (MVPA, M2VPA, and METPA for self-report and accelerometer). Levels of PA were compared among each demographic group using one-way ANOVA. Classification agreement was used to evaluate differences in the proportion of adults who met the guidelines using the 3 PA calculation methods (MVPA, M2VPA and METPA) for both self-report and accelerometer.

Results

A total of 4,773 adults completed both the accelerometer and self-report physical activity measures. Of those, a sub-sample of 3,082 (64.6%) adults met the compliance
criteria for Actigraph wear time and did not have any missing data. When comparing
demographic characteristics of these samples, females made up 52.1% of the total sample
and 50.6% of the sub-sample. Ethnicities were also similar between samples with non-
Hispanic Whites, non-Hispanic Blacks, and Mexican Americans making up 50.0%, 22.8%,
and 20.1% of the total sample, and 51.2%, 21.5%, and 20.6% of the subsample, respectively.
Mean age of the total sample (48.2 y) differed slightly from the subsample (50.5 y) due to
higher levels of compliance among the middle-aged and elderly. The data were statistically
weighted during all analyses according to the subsample to allow for nationally
representative PA estimates.

**Self-report vs. Accelerometer Physical Activity**

Average min/wk of moderate, vigorous, and MET-min PA are displayed by
measurement method and demographic characteristics in Table 1. Levels of PA varied
substantially between measurement methods with self-report estimates exceeding
accelerometer estimates in all cases. Specifically, US adults reported 324.5 ± 18.6 min/wk
(mean ± SE) of moderate PA and 73.6 ± 3.9 min/wk of vigorous PA according to self-report,
and averaged 45.1 ± 4.6 min/wk of moderate PA and 18.6 ± 6.6 min/wk of vigorous PA via
accelerometry.

Despite estimate differences, patterns for weekly PA were similar across
measurement methods for most demographic characteristics. According to both self-report
and accelerometer, PA levels were higher in men than women (Figure 1), higher in non-
Hispanic Whites than non-Hispanic blacks (Figure 2), and higher in normal-weight (BMI <
25) adults than overweight (BMI = 25-30) and obese class I (BMI = 30-35) adults (Figure 3).
Similarly, adults at or above the obese class II threshold (BMI > 35) had the lowest PA levels of all weight-status categories according to self-report and accelerometry.

Physical activity levels among different age groups also shared similar patterns between instruments, such as 20-29 year olds obtaining the most MVPA, with 30-39 year olds obtaining considerably less MVPA (Figure 4). Specifically, 30-39 year olds obtained 22.0% less MVPA than 20-29 year olds according to self-report and 17.3% less MVPA according to accelerometry. Also, 40-49 year olds obtained the second-most PA according to both measures when compared to adults in other age groups.

Some discrepancies between self-report- and accelerometer-measured PA were also evident. Most notably, self-reported levels of MVPA were lowest among Mexican Americans when compared to MVPA levels for non-Hispanic Whites and non-Hispanic Blacks. In contrast, MVPA levels were highest among Mexican Americans according to accelerometry (Figure 2). Physical activity patterns were also very different among Americans aged 70 and older, with self-report MVPA levels lower than all other age groups, while accelerometer MVPA in adults 70+ years old was higher than in both 50-59 year olds and 60-69 year olds.

Table 4 displays MVPA levels for each self-reported domain (transportation, household, leisure, and total) by quartiles of accelerometer MVPA. However, since over half of participants obtained no accelerometer MVPA, a fifth category was created for individuals in this group, with the remaining 4 categories representing quartiles for participants with accelerometer MVPA > 0. Participants who obtained no MVPA according to accelerometry reported various levels of MVPA for each of the following domains: transportation (36.1 ± 4.2), household (129.0 ± 7.7), and leisure (129.9 ± 7.2) MVPA. For individuals with
accelerometer MVPA > 0, self-reported levels of transportation and leisure MVPA increased in a step-wise pattern across the range of accelerometer quartiles (Figure 5). However, no trend in household MVPA was apparent. Instead, participants reported average household MVPA levels between 127.3 min/wk and 148.0 min/wk regardless of accelerometer quartile.

These patterns between accelerometer PA and the self-reported domains of MVPA were also tested using Spearman correlation coefficients due to the skewed data distribution. These correlations confirmed the quartile trends between accelerometer and self-report MVPA (r = 0.27). Specifically, accelerometer MVPA showed a modest relationship with leisure MVPA (r = 0.29), a weak relationship with transportation MVPA (r = 0.20), and very little association with household MVPA (r = 0.08).

**Physical Activity Guidelines for Americans**

The proportion of US adults meeting the Physical Activity Guidelines for Americans (PAGA) was assessed according to levels of MVPA (150 min/wk), M2VPA, (150 min/wk), and METPA (500 MET-min/wk). According to self-report, the proportions of adults meeting the PAGA were 59.6%, 62.0%, and 65.7% using the MVPA, M2VPA, and METPA methods, respectively (Table 2). The proportion of Americans meeting the PAGA according to accelerometry were much lower, with only 8.2% (MVPA), 9.6% (M2VPA), and 44.6% (METPA) of US adults meeting the guidelines (Table 3). The proportion of adults meeting the PAGA guidelines were highest when using the METPA method and lowest when using the MVPA method, regardless of PA measurement method, demographic group (gender, age group, ethnicity), or weight status group. However, there were a small number of individuals who, according to self-report, obtained adequate PA to meet the MVPA and M2VPA guidelines, but did not meet the METPA guidelines. This discrepancy was possible (though
uncommon) because the minimum volume of PA necessary to meet the MVPA and M2VPA thresholds was equivalent to 450 MET-min/wk (150 min * 3.0 METs), which was insufficient to meet the METPA threshold (500 MET-min/wk).

The proportion of adults meeting the PAGA differed very little between the MVPA and M2VPA calculation methods for both self-report (1.4%) and accelerometry (2.4%), indicating relatively low levels of vigorous PA among the population on average. However, more substantial differences between the MVPA and M2VPA estimates were found among some sub-populations (~3-5%), due to relatively greater levels of vigorous PA, and because these sub-groups may have been, on average, relatively closer to (but short of) the PAGA guideline according to the MVPA calculation.

The accelerometer-estimated proportion of US adults obtaining adequate PA according to METPA varied substantially when compared to the MVPA and M2VPA frequencies. These differences may be due to various factors. First, the MVPA and M2VPA guidelines used an average of published MPVA thresholds (19). For the METPA calculation, however, a single Actigraph-based equation for calculating METs was used (24), since no composite equation was available. Since the composite threshold for MVPA (2020 counts/min) was slightly higher than the threshold derived from the MET-min equation (1952 counts/min), activity counts between these thresholds would have counted as PA for the METPA calculation, but not for the MVPA or M2VPA calculations.

Another factor influencing the disagreement between the minute-based and MET-min-based proportions meeting the PAGA was that the METPA calculation was assessed by accumulating MET-min individually, as opposed to MVPA and M2VPA, which counted only PA performed in 10-min bouts. The PAGA specify that the most PA benefits result from
expending a given quantity of energy (500 MET-min) in PA. However, whether or not the benefits that result from this level of PA are contingent upon being performed in 10-min bouts is unclear. Therefore, total METPA levels were of interest in the current study, as a comparison to PA estimates performed in bouts.

**Discussion**

The current study assessed the proportion of US adults who met the PAGA according to self-report and accelerometer measures obtained during NHANES 2005-2006. A secondary purpose of the study was to compare values from these two PA measures in order to gain insight into the self-report and accelerometer relationship.

**Accelerometer Physical Activity Levels in the US**

To date, one study has assessed the physical activity levels of Americans using accelerometry (19). Using data from NHANES 2003-2004, Troiano and colleagues reported that average levels of MVPA performed in 10-min bouts ranged from 3.5 to 10.3 min/d in adult males and from 2.2 to 7.4 min/d in adult females, depending upon their age group. When converted to min/wk, these MVPA values range from 24.5 to 72.1 min/wk for males and 15.4 to 51.8 min/wk for females. Accelerometer results from the current study were similar with males and females obtaining 52.9 min/wk and 37.8 min/wk of MVPA, respectively.

To examine the proportion of Americans obtaining sufficient PA, Troiano’s team estimated adult compliance according to the accumulation of at least 30 min of moderate or vigorous intensity PA in 10-min bouts on at least 5 d/wk (11). For adults aged 20-59 y, 3.8% for males and 3.2% for females obtained sufficient PA to meet the moderate plus vigorous PA guideline. Among adults aged 60+ y, only 2.5% of males and 2.3% of females obtained
the recommended level of PA. Troiano and colleagues did not assess the ACSM/AHA vigorous-intensity guideline separately (i.e., 20 min/d on 3 d/wk).

Of the three guideline-assessment methods in the current study, the MVPA method most closely resembles the guideline used in Troiano’s study since the 150 min/wk guideline is assessed through a simple combination of moderate and vigorous PA. The current study found that 9.5% of men and 7.0% of women achieved the PAGA according to the MVPA assessment method. Though much lower than self-reported estimates, the proportion of adults meeting the guidelines according to accelerometry was substantially higher than those presented by Troiano and colleagues. There are several potential explanations worth noting for this difference in PA levels.

One possibility is that average PA levels increased between the times data were collected in NHANES 2003-2004 to NHANES 2005-2006. This increase in PA is supported by data from the Behavioral Risk Factor Surveillance System (BRFSS) (25). Findings from the BRFSS showed that, according to self-report, the proportion of US adults who met the HP2010 objective for regular physical activity increased by 8.6% in females and 3.5% in males (25).

Another factor that likely contributed to the discrepancy between the proportion who achieved recommended PA levels in Troiano’s study and the current study was that these studies used different PA guidelines. Though participants in both studies had to achieve 150 min/wk of MVPA to meet either guideline, minutes of PA for the ACSM/AHA recommendation had to total at least 30 min on a given day to count towards the weekly total. In contrast, the PAGA does not require a minimum daily total as long as the PA is performed in bouts of at least 10 min. Therefore, it is likely that individuals who accumulated 150
min/wk of MVPA, but did so gradually over several days during the week would have met the PAGA guideline without having met the ASCM/AHA guideline.

In addition, it is likely that some participants obtained fewer than 150 min/wk of MVPA, but met the PAGA in the current study by accumulating at least 75 min/wk of vigorous PA. Since a separate guideline for vigorous activity was not assessed in Troiano’s study, it is reasonable to assume that individuals who met the vigorous guideline, but not the guideline for 150 min/wk of MVPA, would have contributed to the gap in prevalence estimates. According to current study results, however, the average American only obtained 18.6 min/wk of vigorous PA according to accelerometer-based estimates. Therefore, it is unlikely that a large proportion of adults who met the PAGA did so through the vigorous (75 min/wk) guideline. This assumption is reinforced by the fact that the proportion of adults who met the MVPA guidelines (8.2%) differed very little from the proportion who met the M2VPA guidelines (9.6%), in which vigorous PA was doubled.

**Self-report Physical Activity Levels in the US**

Results from the current study showed that 62.0% of US adults achieved the PAGA when using the M2VPA calculation method recommended by the guidelines’ authors (21). Though substantially higher than accelerometer estimates, this proportion of adequate PA among US adults is similar to other self-reported estimates. To date, one study has assessed PA levels according to the PAGA (26). Using self-reported data from the 2007 BRFSS, the study found that 64.5% of U.S. adults obtained sufficient PA to meet the PAGA. These data were obtained according to the M2VPA calculation method, and included the same 3 domains of PA as the NHANES: leisure, transportation, and household activities. However, unlike NHANES, data from the BRFSS were based on a much larger sample (n = 430,912),
which provided self-reported PA data via telephone surveys. In addition, the BRFSS data were collected in 2007 and are, therefore, 1-2 years more recent than the data used in the current study. Even so, the similarity of self-reported results between these two studies is encouraging, and provides support for the validity of the data collection and data weighting procedures used in these two national surveys.

According to the 2007 BRFSS data, 48.8% of respondents met the HP2010 objectives, which consisted of 30+ min/d of at least moderate PA on 5+ d/wk, or 20+ min/d of vigorous PA on 3+ d/wk. These results are similar to previous studies that have used the HP2010 objectives to classify American PA levels (25, 27). Based on the 2007 BRFSS data, assessing American’s activity levels according to the PAGA rather than the HP2010 guidelines resulted in a 15.7% increase in the proportion of the population considered “sufficiently active”. Thus, when compared to previous research, it is likely that the higher rates of physically active Americans in the current study (according to both self-report and accelerometer) result from the change in how the PA guidelines were assessed.

Data from the current study show patterns similar to previous work in which self-reported PA estimates are much greater than accelerometer-based estimates (19, 25-27). Several possibilities exist for this discrepancy. First, self-reported PA may be overestimated since higher activity levels of PA are socially desirable (15). For example, one study examining this link found that social desirability was the strongest predictor of physical activity frequency in 423 adults (18-50 yrs old) (16). However, other research has shown that social desirability only accounted for 1-3% of the variance in self-reported PA levels ($r = 0.11-0.17$) (28).

Misinterpretation of survey questions may also lead to biased results. According to
Baranowski et al., recalling physical activity is a complex cognitive task, which requires respondents to understand ambiguous terms such as “physical activity”, “leisure-time”, and “moderate-intensity” (17). In the current study, household PA was very weakly associated with objectively measured PA. Therefore, it is likely that many individuals interpreted their household activities as moderate-intensity PA, when in actuality they may have been primarily low-intensity PA.

It is also possible that accelerometers underestimate true PA levels. Since monitors are typically worn on the hip (as was the case in the NHANES) they cannot accurately assess upper body activities, nor can they account for movements which require extra effort, such as walking uphill or carrying loads. Though many of the published intensity cut-points account for a wide variety of whole-body activities, these validation studies are primarily based on the most common form of physical activity, locomotor movements. Therefore, low-intensity or non-locomotor PA, such as biking and many household activities, are likely underestimated by accelerometers.

In summary, physical activity estimates among US adults vary substantially depending upon whether measured via self-reported or accelerometer. However, regardless of the measurement method, it appears that using the PAGA instead of the HP2010 guidelines does allow a greater proportion of Americans to be considered active according to both self-report and accelerometry. In addition, when calculating the proportion of Americans meeting the PAGA, it appears that the MVPA, M2VPA, and METPA calculation methods yielded similar estimates. Thus, the current study recommends the M2VPA calculation method since it maintains the simplicity of a minute-based approach while capturing the essence of PA energy expenditure (METPA) that the PAGA are based on.
References


Table 1. Physical activity levels (means & standard errors) in US adults by gender, age group, ethnicity, and weight status according to self-report and accelerometer.

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Table 3. Proportion of US adults meeting the Physical Activity Guidelines for Americans by MVPA, M2VPA, and METPA according to Accelerometer

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Table 4. Self-reported MVPA (min/wk) for activity domains by accelerometer MVPA quartiles. Means and Standard Errors are reported for each domain and total MVPA.

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* Quartiles for Accelerometer MVPA > 0
Figure 1. Physical activity levels in US adults by measurement method.
Figure 2. Self-report (2a) and Accelerometer (2b) physical activity levels by ethnicity in US adults.

Figure 2a.

![Bar chart showing physical activity levels by ethnicity.](chart1)

Figure 2b.

![Bar chart showing physical activity levels by ethnicity.](chart2)
Figure 3. Self-report (3a) and Accelerometer (3b) physical activity levels by weight status in US adults.

Figure 3a.

![Bar chart showing physical activity levels by weight status](image)

- **BMI ≤25**
- **BMI 25-30**
- **BMI 30-35**
- **BMI ≥35**

- **Physical Activity (min/wk)**
  - **Vigorous**
  - **Moderate**

Figure 3b.

![Bar chart showing physical activity levels by weight status](image)

- **BMI ≤25**
- **BMI 25-30**
- **BMI 30-35**
- **BMI ≥35**

- **Physical Activity (min/wk)**
  - **Vigorous**
  - **Moderate**
Figure 4. Self-report (4a) and Accelerometer (4b) physical activity levels by age group in US adults.

Figure 4a.

![Bar chart showing physical activity levels by age group in US adults.]

Figure 4b.

![Bar chart showing physical activity levels by age group in US adults.]

Legend:
- Vigorous
- Moderate
Figure 5. Self-reported MVPA for each physical activity domain by accelerometer MVPA quartiles.
CHAPTER 3
EFFECTS OF ACCELEROMETER COMPLIANCE PROCESSING
ON PHYSICAL ACTIVITY LEVELS IN US ADULTS

A manuscript to be submitted for publication in Medicine and Science in Sports and Exercise
J. M. Tucker, G. J. Welk, N. K. Beyler, S. Nusser

Introduction

Physical activity (PA) is inversely related to several diseases and health problems including coronary heart disease, stroke, type 2 diabetes, osteoporosis, depression, some cancers, and all-cause mortality. It is important to be able to accurately track habitual PA levels so that high-risk populations can be identified, and so that the impact of PA promotions can be evaluated. Valid physical activity measures are also needed to assess the relationship between PA and other health behaviors or outcomes. In short, all field-based PA research hinges on the ability of researchers to accurately assess PA patterns in the population.

Over the past two decades, the use of accelerometry-based activity monitors (commonly referred to as “accelerometers”) has become standard practice for assessing PA in the field. Accelerometers are small, noninvasive, and provide an objective measure of movement (1). These advantages have allowed accelerometers to become widely used and accepted as the preferred method for objectively monitoring PA. However, these devices also have some key limitations. Accelerometers are typically worn on the waist, which allows them to effectively monitor locomotor PA, but this makes them less accurate for activities which produce little trunk movement such as cycling or upper-body activities.

A major challenge for researchers who utilize accelerometers is determining the relationship between the raw data and actual physical activity levels (2). Specifically, these
challenges include determining whether monitors were adequately worn (i.e., participant compliance), choosing how to handle non-wear, and deciding how to process and analyze the raw data to produce PA outcomes (3).

Missing data can have a negative impact on all types of research, potentially leading to selection bias. In accelerometer research, missing data are generally identified in the raw output as a series of minutes during which no data are recorded. Accelerometer non-wear time can accrue when the monitor cannot be worn (e.g., swimming), but is also often due to participants who fail to fully comply with the study requirements. Thus, determining participant compliance based on when and how much data are missing is difficult. Research has demonstrated that participant compliance can have a significant impact on PA results (4). Including monitoring days in which an accelerometer was worn for only a few hours may lead to invalid estimates of PA levels. However, the use of overly strict compliance criteria can cause days or participants to be excluded from analyses.

When considering compliance criteria for an accelerometer study, there are several data processing procedures that must be determined. These criteria may differ depending upon the type of accelerometer since different monitors have different sensitivities and outcomes (i.e., raw counts). Therefore, the present study will refer to common decisions made when analyzing data for Actigraph (formerly CSA) accelerometers. One such decision involves defining the maximum number of minutes an accelerometer can report no movement (zero counts) before that period is removed from the accumulated wear time for a day. Though it is possible for an accelerometer to detect no movement for brief periods while being worn during sedentary tasks, it is unlikely that sustained absences in the data would be possible. Therefore, these periods of missing data are typically counted as non-wear if they
exceed a specified number of minutes. However, no consensus has been established as to what constitutes a period of missing data, and studies have used protocols ranging from 15 min to 60 min in adults, though children’s studies have often used shorter intervals such as 10 min (5-10).

Another important compliance factor involves establishing the number of hours a monitor must be worn to be counted as a “full” day of wear (4, 11). The number of hours used to define a day has varied considerably in previous research. A study by Masse, et al. (11) found that in adult accelerometer studies that reported a wear requirement for a given day, the number of hours ranged from 4 h/d (12) to 12 h/d (13), with 10 h/d as the most common criterion. Typically, the specific days during which participants fail to wear the monitor for the minimum number of hours are excluded from the analyses. Thus, PA outcomes for each subject are based upon an average of only “compliant” days without consideration of weekend and weekdays.

However, the ability of accelerometer data to be representative of an individual’s habitual PA levels may be compromised if only a small proportion of the days the monitor is worn are deemed compliant. Therefore, a minimum number of valid monitoring days is often established to determine whether participants should be excluded entirely from the analyses. This step is necessary because the degree to which the data reflect actual physical activity levels is dependent upon the number of days it is measured (14). For example, results from a subject with only one compliant day of monitor wear will be less likely to represent that person’s actual PA level when compared to results from subjects with seven compliant days. Most previous research has indicated that, in adults, three to six days of valid monitor wear were necessary to obtain reliable data (14-16).
Typically, protocols in which monitors are worn for seven days are recommended, since this practice allows both weekday and weekend periods to be measured, and it provides a balance between participant burden and reliable estimates (17). However, previous studies have based participant inclusion on a minimum number of days ranging from 1 to 8, depending up on the number of days monitored. With studies that use a 7-d monitoring protocol, the minimum number valid days often ranges between 3-5 d, and may include a weekend minimum as well. For example, Cleland et al. (18) required a minimum of 4 compliant days including 1 weekend day, while Eslinger et al. (19) required 5 days including 1 weekend day. However, among the 29 accelerometer studies reviewed by Masse, et al. 3 total days was the most common (52.6%) required minimum, regardless of whether weekdays or weekends (11).

A variety of issues must be considered when deciding on a minimum number of valid monitoring days. A strict criterion may result in data that more closely reflect the actual activity levels of the sample; however, the sample size may be drastically reduced. Of course, requiring a lower number of compliant days will have the opposite effect. Thus, consideration must be taken as to how to optimize the balance between obtaining a valid PA measure (i.e., minimizing measurement error) without excluding too many participants (i.e., minimizing selection bias).

To date, no consensus has been reached regarding the optimal balance in accelerometer compliance criteria. Specifically, little is known regarding how differences in the chosen size of a missing bout of data, the minimum number of hours of valid wear-time for a given day, and the minimum number of valid monitoring days affect the PA outcomes in a study. A better understanding of how these criteria affect study results is needed to help
accelerometer researchers make informed decisions regarding study design, and to improve understanding of potential data processing limitations.

Therefore, the purpose of the current study was to compare the effects of a range of accelerometer compliance processing on resultant PA levels among U.S. adults. By using accelerometer data that is nationally representative of American adults, this study provides a useful summary of how accelerometer compliance processing will likely affect PA outcomes for the general population as well as specific demographic groups. A secondary purpose of the study was to compare associations between body mass index (BMI) and the resultant PA levels across the range of compliance criteria. If differences in the relationship between BMI and the various PA levels exist, then a comparison of these associations may help elucidate which compliance criteria promote the most valid PA outcomes.

Methods

Study Population

Data from the current study were obtained from the National Health and Nutrition Examination Survey (NHANES) 2005-2006. In short, the NHANES is conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (CDC) in order to monitor the health status of the US population. Data for the NHANES are collected year-round as an ongoing series of cross-sectional surveys. The survey uses a multi-stage probability cluster sampling design, which provides nationally representative data, improves data collection feasibility, and allows for the study of sub-populations.

All counties within the US serve as the sampling frame for the NHANES design. For 2005-2006, fifteen single counties (or combinations of small counties) were selected
throughout the country as the primary sampling units. Within these counties, clusters of households were selected, after which one or more persons within each household were recruited for participation. Oversampling of certain subpopulations was performed to increase the reliability and accuracy of health estimates for these groups. In order to account for this oversampling design, the NHANES provided weights for each respondent, which indicated the probability of being sampled. The use of these weights is necessary in order to make valid statistical inferences about the US population from the NHANES sample.

Data for the NHANES 2005-2006 were collected by staff within selected households and in mobile examination centers (MEC). Household surveys were conducted which included questions regarding demographic information. Standardized medical examinations were performed within the MEC usually 1-2 weeks after the household interviews, and included anthropometric measurements including height and weight. In addition, accelerometers were distributed to participants during the MEC visit along with instructions regarding how the monitors were to be worn. All survey instruments, examinations, and instructions were available in English and Spanish.

The current study sample was limited to adults, aged 20 years or older at the time of NHANES 2005-2006. Survey and examination protocols were approved by the NCHS ethics review board and all participants provided informed consent.

**Measures**

**Demographic & Anthropometric Data**

Demographic data were collected during the household interview portion of the NHANES data collection, and included information regarding participants’ age, gender, and race/ethnic group. Participants were categorized according to these demographic groups in
order to allow for comparisons of PA levels. Age was categorized into 6 groups: 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, and 70 years or older. Self-reported race/ethnicity was categorized as non-Hispanic white, non-Hispanic black, Mexican American, other Hispanic, and other race (including multi-racial). The “other Hispanic” and “other race” racial/ethnic groups make up only 3.4% and 4.6% of the total sample, respectively, which prevented reliable sub-categorization of these groups. Thus, participants in these racial/ethnic groups were included in the total sample analyses but are not shown separately. Height (stature) and weight were measured during the MEC exam according to standardized techniques using a calibrated stadiometer and digital scale, respectively (20). Body mass index was calculated by dividing body weight in kilograms by height in meters squared and was provided in the NHANES data set.

**Accelerometer Physical Activity**

Participants in the NHANES were asked to wear a physical activity monitor for 7 consecutive days. The monitor chosen for the NHANES was the Actigraph (Actigraph, LLC; Ft. Walton Beach, FL) model 7164 accelerometer due to its widespread use in clinical and community-based physical activity studies. The Actigraph is a lightweight, uniaxial monitor that records the frequency and intensity of accelerations within the range of normal human motion (21). Monitors were distributed to participants during the MEC examination with instructions regarding how and when it was to be worn. Specifically, monitors were placed on elastic, custom-fitted belts and worn over the right hip throughout the 7-day period. Participants were instructed to begin wearing the monitor the day after the MEC examination and to only remove the device during sleep and water-based activities (e.g., bathing and swimming).
The monitors were programmed to record data in 1-minute intervals (epochs) beginning at 12:01 a.m. the day after the health examination. Subjects were provided with postage-paid padded envelopes in order to return the monitors after the 7-day period. Upon return, monitors were downloaded and checked by the NHANES staff to determine whether they were still correctly calibrated using software provided by the manufacturer. Intensity files were also reviewed for outliers and unreasonable values based on published literature and expert judgment. Data processing procedures specific to the current study are described below.

**Data Processing**

One of the purposes of the current study was to examine the extent to which accelerometer data processing affected PA outcomes among the US adult population. Therefore, several variations in the accelerometer data processing were used to determine the effects of these compliance criteria decisions on resulting PA levels. Key outcomes of interest were mean min/d of total MVPA and mean minutes of MVPA occurring in sustained bouts of 10-min or more.

The determination of adequate accelerometer wear-time was assessed on a daily basis for each participant. The range of compliance criteria for the current study was based on common processing procedures published in previous research. The compliance assessment included the following three components: 1) the maximum length of consecutive non-wear time allowed before that period was removed from the wear-time total for a day, 2) the minimum amount of wear-time for a day to be considered valid, and 3) the minimum number of valid days of accelerometer wear for a participant to be included in the analyses. Each of
these compliance criteria was assessed at three levels of stringency for a total of 27 combinations of compliance guidelines.

When considering bouts of non-wear throughout the day, periods of 20, 40, and 60 minutes of missing data were used to calculate non-wear periods, which were then removed from daily wear-time totals. After daily wear time was established, compliance standards were applied to each day based on a minimum of 8, 10, and 12 hours of wear-time to be considered a valid day of accelerometer wear. Days that failed to meet the minimum wear-time requirement were removed from analyses. After the total number of valid days was established for each participant, participants were screened according to the minimums of 3, 5, and 7 valid days of monitor wear.

Accelerometer results for the current study were based only on participants with at least the minimum number of valid monitoring days. The 27 combinations of compliance criteria listed above were used to determine whether participants were sufficiently compliant throughout 7-d monitoring period. Thus, the accelerometer results for the current study included 27 sets of PA outcomes based on the proportion of compliant participants resulting from each set of criteria. For example, a participant who wore the monitor 9 hrs/day on 4 days would be considered compliant (and included in the analyses) when using the 8 hr/d threshold and the 3 d/wk threshold, but would be considered non-compliant (and would, therefore, be excluded from the analyses) when using the 10 hr/d threshold or the 5 d/wk threshold.

Three PA outcomes were obtained from the accelerometer data: counts per minute (CPM), total minutes per day of moderate plus vigorous physical activity (MVPAt) and minutes per day of moderate plus vigorous physical activity obtained in bouts of 10-min or
To obtain average CPM, the raw accelerometer counts were totaled for all compliant days and divided by the total minutes of wear-time as determined by the compliance criteria. The CPM variable represents the most pure form of physical activity obtained from the data since the calculation is based on the raw accelerometer counts and average daily wear time.

In contrast, intensity cut-points must be applied to the data in order to calculate MVPA from accelerometer counts. Thresholds for the intensity of PA are typically developed using locomotor activities, free-living activities, or a combination of both (2). These cut-points are age-dependent and monitor-dependent. In previous NHANES research, Troiano and colleagues (6) developed an MVPA cut-point based on a weighted average of four published thresholds established for use with adults wearing the Actigraph (22-25). Levels of MVPA for the current study were assessed using Troiano’s cut-point (2020 counts).

Minutes of MVPAt were calculated by summing the accelerometer counts that exceeded the MVPA threshold on days where subjects met the compliance criteria. Levels of MVPAb were similarly assessed, except that only counts that exceeded the MVPA threshold for at least 10 consecutive minutes were accumulated. Similar to previous research, the MVPAb assessment method allowed for 1-2 min below the MVPA threshold during each 10-min bout (6). Average daily MVPAt and MVPAb were calculated by dividing the total min/d for each measure by the number of compliant days for each participant. Only subjects with the minimum number of compliant days (3d, 5d, or 7d) were included in the analyses.

**Data Analyses**
All data processing and analyses were conducted using SAS version 9.2. Statistical analyses were adjusted using the weights provided for the portion of the NHANES sample that wore the activity monitors. Participants were categorized by gender, age, and race/ethnicity in order to compare compliance results and PA levels among these various groups. Weighted descriptive statistics (mean ± SE) were calculated to assess the proportion of compliant participants, average daily wear time, and physical activity levels (counts/min, MVPAt, and MVPAb) for each set of compliance criteria among the US adult population and individual demographics. A mixed model analysis was performed to test whether the conditions yielded significant differences in reported PA levels. The mixed model analyses took into account the repeated nature of the data and allowed the independent and interactive effects of the three compliance factors to be determined. The relationship between PA outcomes was evaluated with correlation analyses. Due to a lack of normality in the data, the relationship between physical activity and adiposity was evaluated using Spearman correlations. The GLM procedure was performed to assess differences in MVPAa among each compliance variable and potential interactions. The Scheffe post-hoc test was used to identify MVPAa differences among compliance levels within each statistically significant factor (i.e., min, hour, and day).

**Results**

The current analyses included 4,153 adults who wore the Actigraph and were not missing anthropometric or demographic data. Table 1 displays the proportion of participants who met the accelerometer wear-time requirements and their average daily wear time for each set compliance criteria. In general, as the strictness of the compliance guidelines increased the proportion of compliant participants dramatically decreased (Figure 1). The average, weighted frequency (mean ± SE) of compliant participants ranged from 89.2% ±
0.50 for the least stringent criteria (60+ min periods of missing data removed with a minimum of 8 hr/d of wear time for 3 days) to 7.4% ± 0.62 for the most stringent criteria (20+ min periods of missing data removed with a minimum of 12 hr/d of wear time for 7 days).

Increasing the strictness of the hour- and day-level guidelines increased the average wear time of participants who met these criteria. However, increasing the stringency of the minute-level guideline had the opposite effect, with progressively lower levels of wear time as the guideline was changed from 60 min to 40 min to 20 min. Thus, the average wear time was lowest (12.6 hr/d ± 0.06) when the 20 min, 8 hr/d, 3d/wk criteria were used, and highest (15.7 hr/d ± 0.08) when the 60 min, 12 hr/d, 7 d/wk criteria were used.

Physical activity outcomes also changed substantially depending upon the accelerometer compliance criteria used (Table 1). Mean CPM ranged from 352.8 ± 18.23 for the least strict criteria to 618.8 ± 132.48 for the strictest criteria. Figure 2 displays CPM across the range of compliance criteria. When keeping the hour-level criteria (10 hr/d) and day-level criteria (5 d) constant, changing the minute criteria from 60 to 20 min resulted in a 61.4 CPM increase. When the minute (40 min) and day (5 d) criteria were held constant, a change from 8 h/d to 12 h/d in minimal wear time resulted in a 37.2 CPM increase. Similarly, holding the minute (40 min) and hours (10 h/d) criteria constant while changing the minimum number of compliant days from 3 to 7 resulted in a 47.8 CPM increase.

Figure 3 shows levels of MVPAt and MVPAb across the range of compliance criteria, while holding one criterion constant in each of the three figures. Overall, average MVPAt ranged from 24.8 ± 1.20 min/d among the least strict compliance guidelines to 50.3 ± 13.25 min/d for the strictest guidelines (Table 1). While holding other compliance variables
constant, changing individual criteria from their least strict to their strictest levels resulted in MVPAt increases of 3.3 min/d, 5.9 min/d, and 4.0 min/d for the minute, hour, and day criteria, respectively.

Average MVPAb ranged from 8.7 ± 1.26 min/d for the least stringent compliance criteria to 29.3 ± 13.00 min/d for the most stringent criteria (Table 1). On average, MVPAb levels were 40.1% of MVPAt levels across the range of compliance criteria. Increasing compliance strictness appeared to have a greater effect on MVPAt than on MVPAb. For example, as a percent of MVPAt, MVPAb levels increased across the range of compliance criteria stringency, from 35.2% of MVPAt levels for the least strict criteria to 58.2% of MVPAt levels for the strictest criteria. Trends in MVPAb were similar to MVPAt when assessing the effects of individual compliance criteria. Holding the two of the three compliance variables constant while changing the third variable individually resulted in MVPAb increases of 1.4 min/d, 4.3 min/d, and 3.1 min/d as the minute, hour, and day criteria, respectively, were changed from their least strict to strictest levels.

Table 2 displays accelerometer compliance variables and PA outcomes by gender, age group, and race/ethnicity. The weighted proportion of compliant accelerometer wear was slightly higher among US men (64.9%) than US women (61.5%), as was the mean wear time (14.3 h/d in men and 14.0 h/d in women). In regards to PA outcomes, CPM were greater in women (357.8 counts/min) than in men (308.6 counts/min), though levels of MVPAt and MVPAb were greater in men. In general, the proportion of compliance was higher among older adults when compared to younger adults. However, daily wear time was highest among middle-aged adults (40-59 y), with lower values among the younger and older age groups. Average CPM was highest among the 20-29 y age group and tended to decline with age,
though MVPAt and MVPAb patterns were less consistent. In regards to race/ethnicity, compliance rates ranged from 52.9% among non-Hispanic Blacks to 65.0% among non-Hispanic Whites, though non-Hispanic Blacks had the highest average daily wear time (14.3 h/d).

Table 3 displays Spearman correlations between BMI and physical activity outcomes across eight levels of accelerometer-wear compliance. In general, correlations were fairly weak and ranged from -0.09 to -0.15 depending upon the level of compliance and the physical activity outcome being compared. Relationships between BMI and MVPAb were strongest, while associations between BMI and CPM were lowest. In regards to levels of accelerometer compliance, associations were only slightly stronger when using a 3-d minimum (-0.14 to -0.15) when compared to a 7-d minimum (-0.10 to -013). No correlation trends were apparent when varying the hour and min compliance variables.

Results from the GLM procedure showed significant differences in MVPAa for the minute (p < 0.0001), hour (p < 0.0001), and day (p = 0.0002) compliance variables. However, none of the potential compliance interactions (i.e., min*hour, min*day, hour*day, and min*hour*day) were statistically significant, though the min*hour and hour*day terms approached significance (p < 0.06). Post-hoc analyses of the main effects revealed higher MVPAa when comparing the 20-min compliance level to the 40-min or 60-min level. For the hour compliance variable, using the 12 h/d requirement led to higher MVPAa levels when compared to the 10 h/d requirement, which in turn resulted in higher MVPAa than the 8 h/d level. Analysis of the day compliance variable showed higher MVPAa levels when comparing 7 d/wk to 3 d/wk, but no differences in activity between the 7 d/wk and 5 d/wk levels, or between the 5 d/wk and 3 d/wk levels.
Discussion

The purpose of this study was to assess the influence of compliance decisions for accelerometer data processing on physical activity outcomes among a representative sample of the US adult population. To date, one study by Masse and colleagues has examined the effects of accelerometer compliance decisions on physical activity results (11). This study compared 4 combinations of accelerometer processing decisions (algorithms) which included combinations of the following compliance decisions: the number of continuous zeros considered non-wear (20 min and 60 min), the minimal daily wear requirement (10 h/d, 12 h/d, 60% of waking time, and 80% of a standard day), and the minimum number of valid days for a participant to be included in analyses (3 d, 4 d, and 7 d using imputation). Results from this investigation showed that changes in compliance decisions did affect physical activity outcomes. The authors concluded that an increase in the number of valid days and the daily wear-time parameters substantially reduced the proportion of compliant participants, with the length of accelerometer inactivity (bouts of zeros) having less of an impact. In contrast, varying the missing data parameter from 20 to 60 minutes produced the greatest reduction in counts per minute when compared to the other compliance parameters. When in combination, the authors concluded that, in general, the more stringent criteria (shorter zero bouts, longer daily wear time, and a greater minimum number of valid days) resulted in increases in MVPA.

Masse and colleagues noted that one limitation of their study was that the sample was fairly homogenous, consisting of 40-70 year old, African American and Hispanic women, who had relatively low physical activity levels. Thus, it may be difficult to generalize the effects of the data processing decisions in this study to other populations. In addition, this
study compared only four combinations of data processing parameters, which limits the ability to interpret other combinations of these compliance decisions. The authors also recognized that the range of decision rules in their study were narrower than those found in the literature, stating that “The comparisons made in this paper are not meant to be exhaustive but to highlight the need to develop standards for accelerometer data reduction” (11).

The present study builds upon previous work by using accelerometer data from a large, nationally representative sample, and by expanding the range of the compliance decisions and the number of compliance combinations included in the analyses. Analyses comparing associations between physical activity and BMI were also examined to determine potential moderating effects. Ultimately, the current study seeks to narrow the range of compliance decisions used in future accelerometer research, in hopes of moving toward a more standardized approach.

**Compliance Outcomes**

In general, results from the current study are consistent with previous research, indicating that stricter compliance levels result in a lower proportion of participants included in the analyses, greater daily wear time, and higher levels of physical activity. As compliance stringency increased, activity level estimates were consistently higher for all three outcome measures (CPM, MVPAt, and MVPAb).

In the current study, the number of participants considered compliant with the accelerometer protocol was substantially impacted by variations in the compliance parameters. When examined individually, the number of compliant days had the largest impact upon the proportion of compliance, followed by the minimum number of hours of
wear time, with the size of the non-wear periods having the smallest effect. For example, all of the 7-d compliance combinations excluded more than half of the original sample, with the proportion of compliance being reduced by 45-56% when changing from a 3-d to a 7-d required minimum. In comparison, adjusting the wear-time requirement from 8 h/d to 12 h/d reduced the proportion of compliant subjects by 17-37%, and changing the non-wear periods from 60 min to 20 min reduced compliance by 4-18% depending upon the other parameters. Therefore, due to the likelihood excessive subject exclusion, it is doubtful that requiring 7 valid days is a feasible option for most studies that incorporate a 7-d monitoring protocol. However, it should also be noted that smaller studies may be able to promote better rates of compliance when compared to larger studies such as the NHANES, due to the potential for more participant training, interaction, and regular follow-up.

Daily wear-time was influenced by the compliance decisions, with levels varying as much as 3.1 h/d. Individually, stricter day (7 d) and hour (12 h/d) parameters resulted in higher daily wear-time, while stricter minute decisions (20 min) caused wear-time to decrease. The influence of the day- and hour-level variables on wear time can be explained by the fact that participants who wore the accelerometer less were more likely to be excluded when compliance levels were strict, resulting in higher average wear time among compliant participants. However, stricter minute-level compliance meant that smaller bouts of missing data (≥20 min vs. ≥60 min) were removed from wear-time totals, resulting in more total minutes of zeros being removed.

**Physical Activity Outcomes**

Results showed that changes in compliance standards produced a greater range of changes in MVPA when compared to CPM. When comparing the most stringent compliance
levels to the least stringent, CPM, MVPAt, and MVPAb were 75%, 103%, and 237% higher, respectively. This large difference in MVPAt and MVPAb appeared to be most highly influenced by changes to the minimum daily wear-time requirement, followed by the minimum number of valid days, and least influenced by the size of the missing bouts that were removed from wear-time totals. In contrast, reducing the size of missing bouts of data had the largest effect on CPM, while increasing the minimum number of valid days had a moderate impact, and changing the minimum hours of daily wear time had the smallest effect.

The relative magnitude of the effect that the minute-level compliance variable had on the physical activity measures can likely be explained by the fact that removing more zeros from the data directly reduces the wear time (denominator) from which CPM is calculated. In contrast, the minute-level decision does not directly affect the amount of time participants spend above the moderate-intensity threshold, unless participants are engaging in physical activity while the monitor is removed. It is also possible that the more compliant participants also tended to obtain more PA, resulting in greater average PA levels as compliance stringency increased. Increasing the number of hours of wear-time may have the potential to reduce the CPM variable because the extended wear-time is likely to overlap more with early morning and late evening periods, during which less physical activity may be occurring. For example, two individuals with the same activity patterns would have differing counts per minute if one removes the monitor during sedentary evening periods, due to differences in wear time. This trend was not apparent in the present study, as activity levels were higher when the minimum hours of wear time increased. Nevertheless, ensuring similar wear-time between participants (e.g., using a continuous, 24-hour protocol) should be a priority when
using CPM. It may also be possible to restrict analyses to specific hours within the day when researching a sample with fairly homogenous schedules, such as elementary school students.

Establishing appropriate wear-time thresholds is also critical when assessing levels of MVPA, as evidenced by the relatively large differences in MVPAt and MVPAb when changing from an 8 h/d to a 12 h/d threshold. There are at least two potential explanations for this occurrence. First, it is likely that some participants are obtaining some MVPA while not wearing the accelerometer, resulting in lower levels of recorded MVPA among the less consistent wearers. It is also possible that those who wear the monitor less on average also tend to be less active on average. This may especially be more likely among elderly participants. These two scenarios highlight the need for a proper balance when establishing a daily wear-time requirement. While it is important that wear-time requirements be high enough to eliminate days in which participants wear the monitor inconsistently, it is also important that individuals who wear the monitor as instructed are not eliminated from the analyses, in order to avoid biasing average activity levels. Results from this study show that PA levels decrease in significant increments when changing from the 12 h/d to the 10 h/d compliance criteria, and from the 10 h/d to the 8 h/d criteria. These lower levels of PA may be indicative of participants with excessive non-wear (i.e., only wearing the monitor for 8-10 h/d) being included in the analyses. When holding other compliance variables constant (at 5 d & 40 min), increasing the wear-time requirement from 8 h/d to 10 h/d reduced the percent of US adults with compliant data by 11%, whereas increasing the requirement from 8 h/d to 12 h/d reduced compliance by 30%. Therefore, it appears that 10 h/d may provide an appropriate balance for the typical adult population between excluding days with excessive non-wear while minimizing subject exclusion.
Previous research has highlighted the need for a minimum number of monitoring days in order to be representative of typical PA levels in adults (14-16,26). These studies have reported the need for a minimum of 3 to 12 days of monitoring in order to obtain reliable PA levels, though the majority of studies found that 3 to 6 days were sufficient. Matthews and colleagues found that among a fairly heterogeneous sample of 122 adults, 3-4 days of monitoring were needed in order to reach 80% reliability for physical activity measures, with 7 days of monitoring resulting in 90% reliability for men and women. Though reliability statistics were not included in the current analyses, the low proportion of compliance that resulted from requiring 7 valid days of data suggest that this requirement may not be feasible for a 7-day monitoring protocol. Furthermore, the current results suggest that PA levels for the 7 d/wk compliance decision were not significantly different from the 5 d/wk PA levels, suggesting that the 5 d/wk decision may be sufficient to capture the majority of occurring PA. Moreover, requiring 7 valid monitoring days may inflate activity estimates if the requirement excludes a large proportion of the sample from the analyses.

When considering the maximum number of consecutive zeros allowed before removing the period, it is important to consider the potential reasons for the absence of counts, and the implications for each. First, it may be possible for several minutes of zeros to be accumulated when the monitor is being worn during a sedentary activity such as watching TV or napping. In this case it would be important that these periods not be excluded from the data since they are compliant periods, which accurately represent the person’s behavior. Second, extended periods of zeros may include times in which the monitor was removed for a legitimate (i.e., compliant) reason, such as while bathing, swimming, or participating in contact sports. Though these periods are not a result of non-compliance, the accumulation of
excessive non-wear for any reason may jeopardize the validity of a monitoring day. Therefore, these compliant periods of non-wear should be excluded from daily wear time. Lastly, monitors may be removed for no legitimate reason (i.e., non-compliance), producing bouts of missing data that should be excluded from wear-time totals. From considering these three sources of zeros in the data, it can be concluded that these bouts should be removed if the monitor is not being worn for any reason. Therefore, determining the number of consecutive zeros to exclude from the data should be based on the likelihood that the accumulation of these zeros could occur while the monitor is being worn, and based on the effect that minute-level compliance decisions can have on PA estimates. Though it has been suggested that adults can remain non-moving for longer periods than can children (14), the authors of the current study hypothesize that it would be uncommon for these motionless periods to exceed 20 minutes, and rarely extend past 40 minutes. Furthermore, results show that PA levels are significantly higher when using the 20-minute criteria when compared to the 40- and 60-minute criteria, suggesting that the removal of more missing periods led to the removal of days and participants with lower average PA levels. Therefore, it is possible that this increase in PA represents a more valid estimate.

The results of the current investigation suggest that changes within the normal range of compliance decisions when processing accelerometer data can have a large impact on the average daily wear-time and physical activity estimates among the US adult population. Based on the proportion of compliant adults and the strength of associations shown between the physical activity outcomes and BMI, it is recommended that accelerometer compliance decisions require at least 3-5 valid days of monitor wear. In addition, it is recommended that a valid day of monitoring require at least 10 hours of wear-time, with periods of consecutive
zeros of at least 20-40 minutes being excluded from this total. Finally, it is vital that researchers clearly report the compliance decisions used when processing accelerometer data, as well as the proportion of compliance and average wear-time for their sample. In doing so, the ability to interpret the validity of accelerometer study results will improve as researchers move closer to establishing standards for accelerometer data reduction.

References


Table 1. Weighted frequency of accelerometer compliance and physical activity outcomes (means and standard errors) by combinations of compliance variables (days, hours, and minutes).

<table>
<thead>
<tr>
<th>Compliance Var.</th>
<th>Compliant (%)</th>
<th>Wear (h/d)</th>
<th>Counts per min</th>
<th>MVPA total</th>
<th>MVPA bouts</th>
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<tbody>
<tr>
<td></td>
<td>Days 1</td>
<td>Hours 2</td>
<td>Min 3</td>
<td>Mean</td>
<td>SEM</td>
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<tr>
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<tr>
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1. Minimum days of valid accelerometer wear to be included in analyses.
2. Minimum hours per day of accelerometer wear to be considered a valid day.
3. Maximum minutes of non-wear before period is excluded from daily wear.
4. Standard Error of the Measure
Table 2. Accelerometer compliance and physical activity outcomes for total US adult population, and by gender, age group, and race/ethnicity.

<table>
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<tr>
<th></th>
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<th>Counts/d</th>
<th>MVPA</th>
<th>BoutMVPA</th>
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<td>SE</td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
</tr>
<tr>
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<td>14.1</td>
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<td><strong>Gender</strong></td>
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Note: Values are based on the reference compliance criteria (5 days, 10 hours, 40 min)
Table 3. Correlations between body mass index (BMI) and counts per min, MVPA total, and MVPA bouts by levels of accelerometer wear-time compliance.

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<th>Min</th>
<th>n</th>
<th>Counts per min</th>
<th>Corr.</th>
<th>P-value</th>
<th>MVPA total</th>
<th>Corr.</th>
<th>P-value</th>
<th>MVPA bouts</th>
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Figure 1. Weighted frequency of participants who passed accelerometer wear-time requirements across three levels of compliance stringency: minutes, hours, and days.
Figure 2. Average counts per minute for 3, 5, and 7 minimum valid days across levels of minute- and hour-level compliance criteria.
Figure 3. Mean MVPA_{t} (min/d) and MVPA_{b} (min/d) across the range of “Day” and “Hour” compliance (top), “Hour” and “Min” compliance (middle), and “Day” and “Min” compliance (bottom).
CHAPTER 4

PHYSICAL ACTIVITY, THE METABOLIC SYNDROME, AND 10-YEAR RISK OF CORONARY HEART DISEASE IN US ADULTS: COMPARISON BETWEEN SELF-REPORT AND ACCELEROMETRY

A manuscript to be submitted for publication to American Journal of Preventive Medicine

J. M. Tucker, G. J. Welk, N. K. Beyler, W. Franke

Introduction

Being physically active is one of the most important ways people can improve their health. According to the 2008 Physical Activity Guidelines for Americans (PAGA), there is strong evidence to support an inverse association between physical activity (PA) and several diseases and health problems including coronary heart disease, stroke, type 2 diabetes, osteoporosis, depression, some cancers, and all-cause mortality (1). In response to these findings, the PAGA recommends that adults obtain 150 min/wk of moderate-intensity activity, 75 minutes of vigorous-intensity activity, or a combination of the two.

Of particular interest in the current study is the association between PA and cardiovascular disease (CVD), the number one killer in the United States (2). In 1996, the Surgeon General’s report on Physical Activity and Health concluded that there was an inverse, dose-response relationship between physical activity and CVD, and coronary heart disease (CHD) in particular (3). In 2008, the PAGA guideline committee reviewed research conducted since the Surgeon General’s report, and this review included more than 60 studies linking self-reported PA and CVD risk (4). According to the summary of prospective cohort and case-control studies, physically active men and women exhibited 20-35% lower CVD and CHD risk (RR = 0.65-0.81 for men; RR = 0.44-0.80 for women) compared to their less active counterparts. The PAGA committee indicated that 60 min/wk of moderate-intensity
activity may be sufficient to reduce CVD risk. However, based on data that supported a dose-response relationship between PA and CVD, they concluded that obtaining greater amount of PA (such as 150 min/wk of moderate-intensity PA) provided a more substantial reduction in CVD risk among previously sedentary individuals (5-7).

In contrast to the substantial literature supporting the link between self-reported PA levels and CVD, evidence regarding the relationship between objectively measured PA and CVD risk is lacking. Previous research has shown that self-reported PA can vary substantially depending upon how it is measured (8). Some literature suggests that self-report tools tend to overestimate true PA levels due to issues regarding social desirability and inability to accurately interpret PA terms such as “moderate-intensity” (9-11). The discrepancy between subjectively- and objectively-measured PA levels has been evidenced by the substantial differences in US adult PA estimates when comparing studies that employed these tools. Self-report data suggest that between 2003-2005, an estimated 45.9% to 46.7% of American adults obtained at least 30 min of moderate-intensity PA on at least 5 d/wk (12,13). Using accelerometry-based activity monitor data from that same time period (2003-2004), Troiano et al. found that less than 5% of the adult population achieved these same PA guidelines (14).

Discrepancies between self-report and accelerometer PA may result from an underestimation of accelerometer PA, an overestimation of self-report PA, or a combination of the two. Potential sources of underestimation when using accelerometers include the inability of monitors to accurately estimate intensities during non-locomotor activities such as cycling, or during locomotor activities that require extra effort such as carrying loads or walking up stairs (15,16). However, it is likely that accelerometers provide PA estimates that
are closer to the truth than self-reported estimates, which if true, suggests that many studies that employ self-reported PA tools may often overestimate true PA levels (17).

Assuming a causal link exists between PA and CVD risk, it can be expected that a measurement tool that facilitates a more valid estimate of PA, such as an accelerometer, would be able to demonstrate a stronger relationship with CVD risk factors. However, little is currently known regarding the relationship between accelerometer-based PA and CVD risk factors. Therefore, the purpose of the current study was to assess the relationship between objectively measured PA and CVD risk factors, including the metabolic syndrome, in the US adult population. In particular, differences in CVD risk were compared between individuals who achieved the PAGA vs. those who did not meet the guidelines. A secondary objective of this study was to compare the relationship between activity levels and CVD risk when using self-report and accelerometer measures of PA in the same sample. It was hypothesized that objectively measured PA estimates would exhibit stronger associations with CVD risk factors when compared to self-reported PA estimates.

**Methods**

**Study Sample**

Data for the current study were obtained from the National Health and Nutrition Examination Survey (NHANES). The NHANES is an ongoing survey conducted by Centers for Disease Control and Prevention (CDC) that provides cross-sectional health information about the US population in two-year intervals. The survey uses a multi-stage probability cluster sampling design, which, when analyzed with the sample weights provided, allows the data to be nationally representative. The NHANES consists of two primary components: an interview and a physical examination. For the current study, self-reported PA levels and
demographic characteristics, including age, race/ethnicity, and education were obtained from the interview portion of the survey. Other variables of interest for this study were collected during the physical examination, and included anthropometric measures such as height, weight, and waist circumference, and cardiovascular risk factors including blood pressure, blood glucose, and blood lipid measures. Accelerometers were also distributed during the physical examination portion of the survey and returned in the mail after the 7-day wear protocol.

The current study included only adults aged 20 years or older. In order to increase the sample size of the current analyses, participants from the NHANES 2003-2004 data set were combined with participants from the NHANES 2005-2006 data set, after which the data were reweighted to allow for nationally representative estimates. After combining samples, there were a total of 9,515 participants who had both self-report and accelerometer data. After screening the data for accelerometer compliance, a total of 6,178 met the minimum wear-time standards (~65%). Missing data for blood pressure, HDL, waist circumference, and BMI further reduced the sample to 5,595 participants with complete data. An additional 15 participants were removed from the analyses due to unrealistic or implausible self-report or accelerometer data, which resulted in a final sample of 5,580 participants. Due to a large number of participants with missing data for triglycerides and blood glucose, analyses that included these variables were performed separately on the sub-sample of participants with these data (n = 2,654).
Physical Activity Measures

Self-Report Physical Activity

Self-reported PA was assessed through a series of questions in which participants reported the activities they had performed during the past 30 days. Activities of at least moderate intensity were reported for each of the following categories: leisure PA, transportation PA, and household PA. In addition, participants reported the frequency of the activity within the past 30 days and the average duration spent performing the activity. For household and transportation PA, each activity was categorized as moderate- or vigorous-intensity based on the established Compendium of Physical Activities (18). For each reported leisure activity, participants were asked whether the pursuit was performed at a moderate or vigorous level. Moderate intensity activities were defined as those that caused light sweating or a slight to moderate increase in breathing or heart rate, whereas vigorous activities included those that caused heavy sweating or a large increase in breathing or heart rate. Total time spent in moderate and vigorous PA for the 30-day period was divided by 4.2857 (30 / 7 d/wk) in order to obtain average min/wk of PA. In order to assess the PAGA, which allow for combinations of moderate PA and vigorous PA, minutes of vigorous activity were multiplied by two before being added to moderate activity. Thus, individuals were categorized as meeting the PAGA (according to self report) if they obtained a total of 150 min/wk of physical activity (MVPAsr).

Accelerometry-based Physical Activity

All ambulatory participants were asked to wear the Actigraph (Actigraph, LLC; Ft. Walton Beach, FL) model 7164 accelerometer for seven consecutive days. Monitors were attached to custom-fitted elastic belts and given to participants with instructions to wear the
monitors over the right hip. Participants were asked to wear the accelerometer during all waking hours with the exception of water-based activities such as bathing or swimming. The monitors were programmed to record data in 1-minute intervals (epochs) throughout the 7-day protocol. Afterwards, monitors were returned in postage-paid padded envelopes, downloaded, and checked for proper calibration.

Accelerometer data processing specific to the current study is described below. Actigraph data were screened in order to assess whether subjects wore the monitors according to study protocol. Specifically, non-wear was assessed by examining the data for periods in which zero acceleration was detected for at least 60 consecutive minutes. After removing these non-wear periods, days in which total wear time was less than 10 h/d were considered invalid and removed from the 7-d totals for each participant. Finally, participants with fewer than at least 4 valid days were excluded entirely from analyses.

The accelerometer data were processed to distinguish moderate and vigorous PA using intensity cut-points that were developed using a weighted average of the relevant thresholds, as has been demonstrated in previous NHANES research (14,19). Specifically, the cut-point differentiated values above 2020 counts/min as moderate PA and values above 5999 counts/min as vigorous PA. Daily activity levels were calculated by dividing total moderate and vigorous PA by the number of compliant monitoring days for each participant. These values were then multiplied by seven to obtain weekly estimates of PA. Similar to the self-report PA estimate, minutes of vigorous activity were multiplied by two before being added to minutes of moderate activity (MVPAa). Participants were then screened according to whether they met the 150 min/wk recommended in the PAGA.
Accelerometer PA that occurred in modified 10-min bouts was also assessed separately. Specifically, minutes of sustained PA (bout-PA) were accumulated if the accelerometer activity counts exceeded the moderate or vigorous cut-point for 10 consecutive minutes with the allowance of up to 2 intervening min below the threshold. For example, 20 min of jogging interrupted by a 2 min stop at a stoplight would result in 18 min of bout-PA. Minutes per week of moderate plus two-times min/wk of vigorous PA performed in bouts (MVPAb) was compared to the PAGA as described above for self-report and individual accelerometer PA using a 150 min/wk threshold.

Clinical Measures

Variables used to assess CVD risk were collected as part of the standard NHANES examination. The specific variables used in the present study include blood pressure, plasma lipid concentrations, plasma glucose concentrations, waist circumference, and body mass index (BMI). Blood pressure was assessed by clinicians who had received special blood pressure training and certification. Each participant underwent a series of three blood pressure measures after having been seated quietly for 5 minutes. An average of the three measures was used to assess systolic blood pressure (SBP) and diastolic blood pressure (DBP) for the current study. If participants were missing any of the three duplicate measures, an average of the available values were used as the SBP and DBP estimates. Blood was drawn during the NHANES examination from which total cholesterol, high-density lipoprotein (HDL), triglycerides, and plasma glucose concentrations were assessed. Triglycerides and plasma glucose values from participants who did not fast for at least six hours prior to the blood draw were excluded from analyses. Waist circumference (WC) was measured to the nearest 0.1 cm immediately above the iliac crest to assess abdominal
adiposity. Body mass index was calculated as weight in kg divided by the square of height in meters.

Criteria from the Third Report of the National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (ATP III) were used to classify CVD risk factors into the following risk categories: elevated blood pressure (systolic >130 mm Hg or diastolic > 85 mm Hg), elevated triglycerides (> 150 mg/dL), low HDL cholesterol (< 40 mg/dL), elevated fasting plasma glucose (>110 mg/dL), and elevated abdominal adiposity (waist circumference > 102 cm in men and > 88 cm in women) (20). Metabolic syndrome was defined by elevated risk in 3 or more of the above risk factors.

The Framingham risk score (FRS) provides another established indicator of CHD risk (21). The current study calculated a modified FRS according to the guidelines in the ATP III report (22) as a continuous summary estimate of CHD risk (based on predicted risk over a 10-year period). Specifically, the FRS calculation involved assigning gender-specific point values based on the following variables: age, total cholesterol, HDL, current smoking status, SBP, and blood pressure medication status (yes/no). Points were then totaled and converted into a 10-year risk estimate using gender-specific tables.

Data Analysis

All analyses used the NHANES examination sample weights in order to provide estimates that were nationally representative of US adults. Weighted descriptive statistics were calculated for the PA measures (MVPAsr, MVPAa, MVPAb) and CVD risk factors by gender, age group, race/ethnicity, and for the total sample. Spearman correlations were calculated separately by gender to evaluate gender-specific relationships between PA levels
and FRS. Partial Spearman correlations were used to assess these relationships while controlling for age, race/ethnicity, education, BMI, and smoking status. Significant differences between correlations were assessed using the Fisher r-to-z transformation test.

Multiple logistic regression analyses were used to estimate odds ratios (OR) for elevated blood pressure, HDL, triglycerides, blood glucose, waist circumference, and the metabolic syndrome for individuals who met the PAGA compared to those who did not achieve the guidelines. The regression models were conducted separately by gender for both self-report and accelerometer PA, and were weighted to provide nationally representative OR estimates. Four models were assessed including an unadjusted model (model 1), a model that controlled for demographic factors including age, race/ethnicity, and education (model 2), a model that controlled for demographic factors plus smoking (model 3), and a model that controlled for demographic factors, smoking, and BMI (model 4). The Fisher r-to-z transformation was conducted using an online calculation tool designed for this purpose (23). All other statistical analyses were conducted using SAS version 9.2 (SAS Institute, Inc., Cary, NC).

Results

Summary measures for PA, individual CVD risk factors, and FRS are described by demographic characteristics in Table 1. Physical activity estimates varied widely between total MVPAsr (448.6 min/wk), MVPAa (176.1 min/wk), and MVPAb (47.2 min/wk). All PA estimates were greater in males than in females, though the gender difference was larger for MVPAa (43.2% lower in women) than for MVPAsr (21.8% lower in women) and MVPAb (25.9% lower in women). In addition, levels of MVPAa declined in a step-wise fashion as age groups increased, but the relationship between self-reported PA and age group was less
consistent. Disparities in PA trends were also apparent when comparing self-report to accelerometer measures among different race/ethnicities. Specifically, MVPAsr was highest among non-Hispanic Whites and lowest among Mexican Americans, while MVPAa and MVPAb were highest among Mexican Americans when compared to other race/ethnicities.

Table 2 displays Spearman correlations and Spearman partial correlations between the PA estimates and FRS with potentially confounding variables separately and collectively controlled. For males and females, the unadjusted relationship between PA and FRS was strongest for MVPAa (Males: r = -0.57, Females: r = -0.50) and weakest for MVPAsr (Males: r = -0.08, Females: r = -0.19). Controlling for race/ethnicity, education level, BMI, and smoking status had little effect on the association between PA and FRS. However, controlling for age weakened the PA and FRS relationship substantially, with the largest reductions occurring in age-adjusted MVPAa for both males (r = -0.11) and females (r = -0.18). When comparing genders, the unadjusted relationship between PA and FRS was stronger in men than in women for both MVPAa (p = 0.0002) and MVPAb (p = 0.005). However, the unadjusted correlation between MVPAsr and FRS was significantly higher (p < 0.0001) in women (r = -0.19) than in men (r = -0.08).

Table 3 (males) and table 4 (females) display the odds of having elevated risk for each of the five factors for metabolic syndrome or for the condition itself when comparing those who met or failed to meet the PAGA according to self-report and accelerometry. In general, those who failed to meet the PAGA according to accelerometry exhibited greater odds of elevated risk for most indices of the metabolic syndrome when compared to self-report. However, the most notable exception to this trend included a significantly greater risk for metabolic syndrome among women who failed to meet the guidelines according to
MVPAsr (OR = 1.49) when compared to the non-significant increase in risk for MVPAa (OR = 1.28) and MVPAb (OR = 1.44), after adjusting for all potential confounders (model 4). In contrast, adjusted odds ratios for metabolic syndrome in men were highest for MVPAa (OR = 2.06), when compared to the non-significant odds ratios for MVPAb (OR = 1.46) or MVPAsr (OR = 1.07).

When examining individual risk factors, MVPAa was the only PA measure that showed a significantly increased odds of elevated blood pressure in both men (OR = 1.34) and women (OR = 1.34) after controlling for potential confounders. Similarly, the only significant OR for waist circumference resulted from men (OR = 1.62) and women (OR = 1.56) who were classified according to levels of MVPAa. For HDL levels, MVPAb provided the highest adjusted odds ratios for both males (OR = 2.02) and females (OR = 3.43), though MVPAa was also a significant predictor in males (OR = 1.65). For elevated odds of low HDL in females, MVPAsr (OR = 1.57) provided the only significant OR after controlling for confounding variables, despite the larger OR estimates from MVPAa and MVPAb. Odds of having elevated glucose levels when failing to meet the PAGA were significant for unadjusted estimates in both genders, but not for estimates after adjustment for confounding variables. In males, adjusted odds of increased triglyceride levels were also non-significant. In contrast, all three PA measures significantly differentiated adjusted odds of elevated triglycerides in females, with the highest OR among MVPAb (OR = 2.06) when compared to MVPAa (OR = 1.83) and MVPAsr (OR = 1.50).

**Discussion**

The present study demonstrates the impact of different of PA measurement methods on levels of PA and relationships between PA and health-related outcomes. Results from this
study suggest that accelerometer-based PA estimates are substantially lower than self-reported estimates in this nationally representative sample of US adults. Relationships with metabolic syndrome, measured indirectly through CHD risk estimates, are also more strongly associated with PA levels when assessed with a more objective method (i.e., an activity monitor).

When examining the relationships between PA measures and FRS, MVPAa and MVPAb were significantly associated with elevated CHD risk in both genders after controlling for age, race/ethnicity, education, smoking, and BMI. Alternatively, MVPAsr was significantly associated with FRS in females only, and provided the weakest relationship with FRS for both genders when compared to accelerometry. Adjusting for most potential confounders individually had little effect on the PA and FRS relationship, with the exception of age, which weakened the correlation between MVPAa and FRS from -0.57 to -0.11 in males and from -0.50 to -0.18 in females. As shown in table 1, levels of MVPAa decreased in a step-wise fashion with age, findings which are consistent with increased CHD risk with age. Age is used in the calculation to estimate future risk of CHD in the FRS so it is not surprising that correlations were blunted when controlling for this variable.

Results from the logistic regression analyses suggest that, in general, objectively measured PA provide a better differentiation of cardiovascular health risks better than does self-reported PA. It is likely that the attenuated relationship between self-reported PA and CVD risks was due, in part, to greater error in the self-reported measure when compared to the objective measure. The unadjusted odds for all 5 metabolic syndrome risk factors were significant when classified by MVPAa levels in both males and females. When classified by MVPAb, 4 out of 5 unadjusted odds ratios were significant for both genders. For MVPAsr,
only 1 out of 5 unadjusted odds ratios was significant for males, though all 5 were significant for females. The reason behind this gender difference for self-reported PA is unclear. While it is possible that PA affects females’ cardiovascular risks differently than it does for males, this seems unlikely due to the fact that lower levels of accelerometer PA provided similarly elevated odds for both genders. It is also possible that, on average, females are able to report their PA levels more accurately than males, resulting in stronger links between self-reported PA and cardiovascular health. However, a recent review comparing self-reported PA to direct PA measures failed to find any systematic differences in regards to gender (24), and some research has even shown greater self-report accuracy in males compared to females (25).

Self-reported PA for the current study may also be more valid for females than for males, since it is likely that males obtain more occupational PA than females; this was a PA domain not captured in the NHANES.

The current study included 4 regression models in order to compare the effects of potentially confounding variables on the PA and metabolic syndrome relationship. Controlling for demographic factors such as age, race/ethnicity, and education (model 2) had a moderate impact on the odds of elevated blood glucose, waist circumference, and the metabolic syndrome, but had little effect on the remaining variables. Adjustment for smoking status (model 3) had minimal impact on any of the metabolic syndrome risk factors. However, controlling for BMI (model 4) had a substantial impact on the odds ratios for several risk factors. For males, adjustment for BMI reduced the MVPAa odds ratios for triglycerides, glucose, and the metabolic syndrome to non-significance. Also, adjustment for BMI in male MVPAb levels reduced the OR for waist circumference to non-significance. For females, adjustment for BMI reduced MVPAa OR for HDL and metabolic syndrome to non-
significance, and did the same to MVPAb odds ratios for blood pressure, HDL, waist circumference, and the metabolic syndrome. For levels of MVPAsr, controlling for BMI reduced the odds of elevated waist circumference to non-significance for both genders. This large reduction in the waist circumference odds ratios for all PA measures is logical, due to the strong relationship between BMI and waist circumference. The large impact that controlling for BMI had on the relationship between accelerometer PA and other metabolic syndrome risk factors suggests that PA reduces the cardiovascular risk, in part, through its effect on weight management. However, due to the cross-sectional nature of this study, it cannot be determined whether weight status is, instead, influencing PA levels in addition to affecting cardiovascular risks.

To date, this is the first study to compare self-reported and accelerometer PA to health-related factors. However, previous studies have assessed cardiovascular health outcomes with self-reported PA and other objective indicators. Blair, et al. found that objective measures of aerobic fitness were more closely linked to CVD risk factors than was self-reported PA estimates (26). Another study by Schmidt, et al. compared several PA estimates including a 7-day pedometer protocol and the International Physical Activity Questionnaire (IPAQ) with cardiometabolic health risks in young Australian adults (27). When comparing PA estimates to CVD health risks using partial Spearman correlations the authors found estimates ranging from -0.12 to 0.14 for the IPAQ (met hr/wk) and from -0.17 to 0.12 for the pedometer (steps/d). Schmidt and colleagues concluded that associations between PA and health were not uniformly stronger for the pedometer when compared to self-report. For example, pedometer PA was more strongly related to waist circumference,
while leisure time and vigorous-intensity PA from the IPAQ showed stronger associations with insulin resistance.

However, it is worth noting several factors when comparing the results of Schmidt’s study with those of the current study. First, pedometer steps, though objectively measured, are unable to capture PA intensity, which has been shown to be an important factor in determining cardiovascular risk (28). Second, it is likely that the younger ages of the participants in Schmidt’s study account for, at least in part, the weaker associations between PA and CVD risk when compared to the current study results. Thus, it is possible that examining a population at greater risk for CVD would have helped to further elucidate the relationship that each PA measure had with cardiometabolic risk. Third, it is possible that the IPAQ provides a more complete measure of PA when compared to the questionnaire used in the NHANES, since the NHANES does not include occupational PA. According to Schmidt’s study, occupational PA was the most highly correlated domain of self-reported PA when compared to pedometer steps in men. In the past, leisure PA has often been targeted in the literature since it is the most modifiable form of PA, though research has shown that other domains of PA can also have a positive effect on health (29). Therefore, though the inclusion of occupational PA would have further increased the discrepancy between subjective and objective PA in the current study, it may have also increased the associations between self-reported PA and health risks.

Previous research has shown that moderate to high levels of self-reported PA are independently associated with lower 10-year risk of CHD in both males and females (30). Results from the current study also support a weak, but significant relationship between self-reported PA and cardiovascular health. Furthermore, the current study shows that objectively
monitored PA levels yield a more substantial relationship with FRS and risk factors for the metabolic syndrome when compared to self-reported PA. It is noteworthy that the study did not indicate additional benefits of obtaining PA in sustained bouts (MVPAb) compared to accumulation of PA (MVPAa). In fact, odds ratios for cardiovascular risk factors tended to be higher when participants were categorized according to MVPAa levels when compared to MVPAb levels, though exceptions did exist such as for HDL levels.

In the past, the vast majority of epidemiological research for PA has relied on self-reported measures due to cost and feasibility. However, several recent investigations have incorporated accelerometry into large, epidemiological samples (14, 30-32). Results from the current study suggest that the use of accelerometers may provide a more valid estimate of PA among the US adult population when compared to the NHANES self-report tool.

The associations observed between PA and CHD risk are lower than typically reported for associations between fitness and CHD risk factors (24,33). It is important to acknowledge that PA was assessed in this study with a single 7-day monitoring period. While this protocol has been viewed as sufficient to capture free living PA reliably (34), it is likely that improved results could have been obtained if PA was assessed with more precision and over a longer period of time. As technology and monitoring protocols continue to advance, it is possible that there would be corresponding improvements in the reliability and validity of PA assessment. These advances will allow PA to be assessed with less error and increase power needed to further explore the benefits of PA on health. It is possible that differences in health-related associations between fitness and PA would be less pronounced if the trait variable of habitual PA behavior could be assessed as objectively as the state variable of fitness. Further research is clearly needed to examine these issues.
In summary, the current study demonstrates that the objective assessments of PA in the NHANES provide a more effective indicator of PA than the currently available self-report tool. The results also provide some of the first evidence to demonstrate that compliance with the PAGA recommendations provides clear health benefits (as assessed by differences in CHD risk). Specifically, these findings indicate that adults who engage in 150 min/wk of moderate and vigorous PA are less likely to experience adverse cardiovascular risks.

References


Table 1. Weighted means and standard errors for cardiovascular risk factors and physical activity levels by demographic characteristics.

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<tr>
<th></th>
<th>HDL Chol</th>
<th>Triglycerides</th>
<th>Glucose</th>
<th>Waist (cm)</th>
<th>SBP</th>
<th>DBP</th>
<th>10-y CHD</th>
<th>SR MVPA</th>
<th>Acc MVPA</th>
<th>Bout MVPA</th>
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</thead>
<tbody>
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<td>Mean</td>
<td>SE</td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
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<td>96.9</td>
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<td>103.4</td>
<td>0.81</td>
<td>100.5</td>
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Table 2. Spearman correlations between measures of physical activity and 10-year Framingham Risk Score (FRS) for coronary heart disease.

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<th>Bout Accelerometer</th>
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Table 3. Male odds ratios for metabolic syndrome and its risk factors according to self-reported (SR), individual accelerometer (Acc), and bout accelerometer (Bout) physical activity levels (150 min/wk).

<table>
<thead>
<tr>
<th></th>
<th>Model 1 Unadjusted</th>
<th>Model 2 Demo adjusted</th>
<th>Model 3 Smk added</th>
<th>Model 4 BMI added</th>
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<td><strong>BP</strong></td>
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<tr>
<td>SR</td>
<td>1.13 0.92-1.39</td>
<td>1.11 0.86-1.43</td>
<td>1.12 0.86-1.45</td>
<td>1.09 0.83-1.42</td>
</tr>
<tr>
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<td>2.28 1.85-2.80</td>
<td>1.49 1.17-1.91</td>
<td>1.50 1.18-1.90</td>
<td>1.34 1.03-1.75</td>
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<td>1.21 0.88-1.66</td>
<td>1.22 0.88-1.68</td>
<td>1.12 0.80-1.56</td>
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<tr>
<td>SR</td>
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<td>1.22 0.94-1.59</td>
<td>1.16 0.90-1.50</td>
</tr>
<tr>
<td>Acc</td>
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<td>1.65 1.27-2.14</td>
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<tr>
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<td>2.02 1.32-3.08</td>
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<td>1.10 0.84-1.45</td>
<td>1.04 0.80-1.36</td>
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<tr>
<td>Acc</td>
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<td>1.55 1.15-2.08</td>
<td>1.55 1.16-2.09</td>
<td>1.29 0.95-1.74</td>
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<tr>
<td>Bout</td>
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<td>0.95 0.61-1.49</td>
<td>0.95 0.61-1.50</td>
<td>0.80 0.50-1.28</td>
</tr>
<tr>
<td><strong>Glucose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
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<td>0.86 0.68-1.11</td>
<td>0.86 0.68-1.10</td>
<td>0.81 0.65-1.01</td>
</tr>
<tr>
<td>Acc</td>
<td>2.68 1.88-3.80</td>
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<td>1.25 0.86-1.83</td>
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<td></td>
<td></td>
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<tr>
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<td>1.54 1.25-1.91</td>
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<td>1.62 1.12-2.34</td>
</tr>
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<td>2.10 1.45-3.06</td>
<td>1.53 0.76-3.09</td>
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<tr>
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<td>2.06 1.04-4.09</td>
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Table 4. Female odds ratios for metabolic syndrome and its risk factors according to self-reported (SR), individual accelerometer (Acc), and bout accelerometer (Bout) physical activity levels (150 min/wk).

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<th>Model 1 Unadjusted OR 95% CI</th>
<th>Model 2 Demo adjusted OR 95% CI</th>
<th>Model 3 Smk added OR 95% CI</th>
<th>Model 4 BMI added OR 95% CI</th>
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<tr>
<td><strong>HDL</strong></td>
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<td></td>
<td></td>
<td></td>
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<td>SR</td>
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<td>1.67 1.11-2.51</td>
<td>1.57 1.02-2.40</td>
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<tr>
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<td>1.95 1.14-3.34</td>
<td>1.85 1.09-3.17</td>
<td>1.83 1.07-3.11</td>
<td>1.58 0.91-2.73</td>
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<td>1.83 1.23-2.70</td>
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<td>SR</td>
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<td>1.30 1.06-1.60</td>
<td>1.32 0.92-1.88</td>
</tr>
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<td>Acc</td>
<td>4.40 2.65-7.31</td>
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SUMMARY

In 2008 the U.S. Department of Health and Human Services issued the first government-sponsored Physical Activity Guidelines for Americans (PAGA), which provided an update regarding physical activity (PA) and health, and included age-appropriate recommendations for the US population. For aerobic PA, the PAGA concluded that adults should accumulate 150 min/wk of moderate-intensity activity, 75 min/wk of vigorous-intensity activity, or a combination of the two. Though similar to previous recommendations, the PAGA contains important differences that potentially affect the proportion of adults who obtain them. In addition, little evidence is currently available regarding the health implications that these new guideline provide.

Previous research, using self-reported PA, has shown similar, though relatively low, PA levels throughout the past decade. However, a recent study based on objectively measured PA data from the National Health and Nutrition Examination Survey (NHANES) found drastically lower levels of PA among the US adult population. These findings have highlighted concerns regarding the discordance among PA measurement tools, such as a limited ability to estimate current PA levels, and a reduced interpretability and comparability of research findings that use these instruments. The purpose of this dissertation was to compare self-reported and objectively measured PA in order to help clarify PA outcomes and health-related relationships among the adult population.

Study 1 of the dissertation assessed the proportion of US adults who obtained the PAGA according to self-report and accelerometry-based activity monitors. The PAGA provide different moderate- and vigorous-intensity PA recommendations in order to achieve a similar energy expenditure goal. Therefore, to allow for combinations of both moderate and
vigorous PA, study 1 also included three methods for calculating PA levels; moderate plus vigorous physical activity (MVPA), moderate plus two-times vigorous physical activity (M2VPA), and MET-minutes of physical activity (METPA). Results from this study highlighted the large differences between self-reported and accelerometry-based PA levels. According to self-report, 59.6% of adults obtained 150 min/wk of MVPA, but according to accelerometry only 8.2% of adults reached this threshold. These results highlight two important points. First, the discrepancy between self-report and objectively measured PA is wide. Second, when compared to previous studies that have assessed former guidelines, the present proportion of active Americans is slightly higher (with respect to the measurement methods), suggesting that the PAGA may be slightly easier to obtain.

When comparing self-report and accelerometer PA levels, differences between demographic groups were not always consistent between the two measures. For example, self-reported PA was lowest among Mexican Americans though accelerometry-based levels were highest among this group. When the sample was divided into 5 levels of accelerometer PA, participants who obtained 0 min/wk of accelerometer MVPA reported more MVPA (390 min/wk) than did participants in the next two levels of accelerometer MVPA. These results suggest not only a large, overall difference in PA outcomes, but poor agreement between the two measures as well.

Despite these large differences between subjective and objective PA levels, neither is considered a gold standard, which makes it difficult to determine which provides a more valid measure. Though accelerometer PA is typically considered more accurate than self-reported PA, there are data processing issues that limit the interpretability of accelerometry results. One such issue involves the way in which monitor-wearing compliance is
determined. Differences in compliance standards affect not only the sample size of a study, but can also affect the resulting PA estimates. Therefore, the purpose of study 2 of the dissertation was to compare the effects that a normal range of potential compliance decisions would have on resulting physical activity levels among US adults. Results of this investigation showed that these data processing decisions had a substantial impact upon the proportion of compliance (which ranged from 7.4% to 89.2%), as well as upon PA levels measured in counts per minute (which ranged from 352.8 to 618.8) and levels of MVPA (which ranged from 24.8 min/wk to 50.3 min/wk). These large differences in PA estimates highlight the need for consistent compliance processing standards in the literature. Therefore, based on the results of study 2, it was recommended that accelerometer researchers require between 3 to 5 valid days of accelerometer wear when using a 7-d protocol. It was further recommended that a minimum of 10 hours of wear-time be required for a day to be considered valid. Lastly, it was suggested that periods of consecutive zeros in the data be removed from wear-time totals if they exceed 20-40 minutes in duration. This combination provides a reasonable balance between valid PA estimates and participant non-compliance. The use of these standardized processing recommendations would reduce variability and greatly improve the comparability of study results.

Study 3 of the dissertation incorporated the above recommendations while comparing the relationship between risk factors for coronary heart disease (CHD) and self-reported and objective PA levels. Specifically, the purpose of study 3 was to assess the effects that obtaining the PAGA would have on two indicators of cardiometabolic risk: the Framingham risk score (FRS) and the metabolic syndrome. A secondary purpose was to compare the strength of the relationships between these health factors and three PA measures: self-
reported (MVPAsr), accelerometer (MVPAa), and accelerometer activity obtained in 10-min bouts (MVPAb). This study built upon study 1 by incorporating the calculation developed to combine moderate and vigorous PA when assessing fulfillment of the PAGA. Overall, results showed that obtaining the PAGA threshold provided substantial health benefits when compared to those who did not meet the guidelines, especially when measured via accelerometry. After controlling for age, race/ethnicity, education, and smoking status, males who failed to obtain the 150 min/wk of MVPAa had a 1.5 times greater odds of having elevated blood pressure, 1.99 times greater odds of having low HDL, 1.55 times greater odds of having elevated triglycerides, 1.57 greater odds of having elevated blood glucose, 2.19 times greater odds of having elevated waist circumference, and a 2.1 times greater odds of having the metabolic syndrome when compared to males who obtained 150 min/wk or more of MVPAa. Women who did not meet the PAGA according to MVPAa showed similar adverse health risks with a 1.6 times greater odds of having elevated BP, 1.83 times greater odds of having elevated HDL, 2.29 times greater odds of having elevated triglycerides, 2.13 times greater odds of having elevated waist circumference, and 2.30 times greater risk of having the metabolic syndrome when compared to their more active counterparts. Differences in health risks were less pronounced when separating participants by levels of MVPAsr, especially among males. After adjusting for the same confounding variables, males who did not meet the PAGA according to MVPAsr had a 1.54 times greater odds of having elevated waist circumference only. Females who failed to report sufficient MVPAsr to meet the guidelines had a 1.67 times greater odds of having low HDL, 1.55 times greater odds of having elevated triglycerides, 1.30 times greater odds of having elevated waist circumference, and 1.66 times greater odds of having the metabolic syndrome. These results
provide two important conclusions. First, obtaining MVPA sufficient to meet the PAGA results in substantial health benefits. Second, objective estimates of PA levels from an accelerometry-based monitor provide a much stronger relationship with health-related variables in the present study when compared to self-reported PA.

The results from these studies provide important epidemiological information about the PA levels of US adults in relation to the PAGA, and advance research on the importance of meeting these guidelines to promote cardiovascular health. In addition, these studies help to clarify the relationship between self-reported and objective PA levels among the US adult population as a whole, and among individual demographic groups. While the NHANES self-report measure provides a convenient and low cost indicator of PA in the population, it appears less useful in predicting cardiovascular risk when compared to accelerometry, and perhaps less valid overall. The incorporation of objective PA assessments, such as accelerometers, should be encouraged for use in future epidemiological and health-related research whenever possible.