PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR: MEASUREMENT APPROACHES AND THEIR RELATIONSHIPS WITH CARDIOMETABOLIC HEALTH INDICATORS AMONG COLLEGE FRESHMEN

by

JILL MARIE LUCAS

(Under the Direction of Michael D. Schmidt)

ABSTRACT

The physical activity (PA) and sedentary behavior (SED) levels of college students may be related to their cardiometabolic health. This study aimed to assess the relationships between measures of PA and SED with each other and a criterion measure and their respective associations with cardiometabolic risk indicators among college freshmen. Students (n = 402; age = 18.3 ± 0.5 years; 68.7% female) completed the Godin Leisure Time Questionnaire, the IPAQ, the GPAQ, and a television viewing question, and wore a New Lifestyles 1000 (NL) accelerometer. A subgroup (n = 54) also wore an activPAL. Cardiometabolic risk was indicated by HOMA, C-reactive protein (CRP), android body fat (BF%), and the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) risk score.

ActivPAL steps were associated with Godin vigorous activity, IPAQ travel activity, and NL steps, and aerobic steps were associated with Godin total vigorous activity and NL steps and activity minutes [model R^2 = 0.76 and 0.68, respectively, $p < 0.001$]. ActivPAL sitting time was independently associated with television time and NL steps [model $R^2 = 0.14$, $p = 0.02$]. NL steps and Godin total activity independently predicted BF% for PA measures [model $R^2 = 0.35$ and 0.34, respectively, $p < 0.001$]. Adjusted for gender, significant associations between HOMA and the PA measures of NL steps and Godin total activity were seen (highest quartile of PA had 50% reduced prevalence compared to lowest group, $p < 0.10$). Television was associated with CRP (91% increased prevalence in highest third compared to lowest, $p = 0.05$). Regression analyses did not retain any multiple measure models across outcomes. Latent variables did not have a greater predictive ability of activPAL measures or cardiometabolic outcomes than field measures. No interaction effect was present between levels of PA and SED or with BF%.

The findings suggest that NL steps and Godin measures were mostly strongly associated with activPAL criterion estimates and with cardiometabolic risk in college students. Latent variables were not superior to individual measures. Future work should seek methods of combining complementary measures to improve predictive ability in college students.

INDEX WORDS: Physical activity, sedentary behavior, measurement, cardiometabolic health, college students

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CHAPTER 1

INTRODUCTION

1.1 Significance

Despite substantial declines in the mortality rates associated with cardiometabolic diseases over the past four decades, these conditions remain the leading cause of morbidity and mortality in the United States. Additionally, cardiometabolic diseases present an enormous burden on society in terms of life-years lost, diminished quality of life, and both direct and indirect medical costs [1]. Though the increasing prevalence of obesity and diabetes and growth in the older population contribute to this burden, it has also become clear that many cardiometabolic diseases with ultimate outcomes in adulthood have their origins early in life [1]. The atherosclerotic process begins in childhood with fibrous plaques beginning to appear during the adolescent and early adulthood years [2]. Trends of increasing obesity and severe obesity rates and an increasing prevalence of hypertension and type 2 diabetes among the pediatric population may contribute to further increases in the disease burden, and at a younger age [1]. Multiple studies, including the Bogalusa Heart Study and the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) Study, have demonstrated that adverse levels of coronary heart disease risk factors present among adolescents and young adults are associated with both early and advanced lesions, decades before disease onset [3]. These risk factors tend to track into adulthood [4].

Fortunately, disease risk may be modified through several health behaviors, including physical activity [5]. The relationships between physical activity participation and health outcomes are well-established [6-8]. The preventive role of moderate- to vigorous-intensity physical activity in cardiovascular disease, type 2 diabetes, and obesity is agreed upon by clinicians, exercise scientists, and public health experts alike [9]. In 2008, the *Physical Activity Guidelines for Americans* were updated to detail the types of physical activity, including aerobic, moderate, vigorous, lifestyle, and strengthening/resistance, that influence health status, quality of life, and physical functioning [7, 10]. These guidelines encourage people to participate in at least 30 minutes of moderate-intensity physical activity (accumulated in bouts of at least 10 minutes) for five or more days or relatively more intense activity for less time (75 minutes per week).

Though adequate participation in physical activity is crucial, the greatest proportion of the waking day is not spent in moderate- to vigorous-intensity activity [9]. Changes in society and technological advancements have reduced the requirement for daily physical activity by humans. Much of the time previously spent in lighter intensity activities, such as for transportation, workplace requirements, and domestic chores has been replaced by sedentary behaviors [11, 12]. Increases in sedentary options, including motor vehicle travel and screen-focused activities such as television watching, computer usage, and video game playing, further contribute to reductions in physical activity [13-17]. Sedentary behaviors can be characterized by both their energy expenditure and posture, with a more standardized and accepted definition being established over the past several years. By definition, sedentary behaviors result in an energy expenditure of no more than 1.5 times basal energy expenditure (i.e. 1.5 METs) and are performed in a sitting, reclining, or lying down position during waking hours [12, 18, 19]. Though this area of research is in its relative infancy, a rapid accumulation of evidence has indicated that the amount of time spent in sedentary pursuits may be independently associated with lower levels of total physical activity energy expenditure, an increased risk of weight gain, and an increased risk of many adverse health outcomes.

More specifically, epidemiological evidence from both cross sectional and prospective observational studies indicate that sedentary behavior is a distinct risk factor for biomarkers of diabetes risk and with diabetes itself [16, 20-25]. An analysis of the NIH-AARP Diet and Health study data found double the risk of cardiovascular disease-related death among adults who watched seven or more hours of television a day compared to those who watched less than one hour, despite more than seven hours per week of moderate-to-vigorous physical activity participation among both groups [26]. Objectively-measured sedentary behavior has been deleteriously associated with numerous cardiometabolic biomarkers, including waist circumference, blood glucose, triglycerides, and the inflammatory biomarker C-reactive protein, generally independent of moderate-to-vigorous physical activity [20, 27, 28]. Although a fairly consistent pattern of findings has been observed, the limited number of studies, inconsistencies in earlier studies regarding the definition of sedentary behavior, mixed results with some outcomes, and potential shortcomings with measurement of the behavior leave a substantial need for more research in the area [15].

The measurement of physical activity and sedentary behavior is an increasingly prevalent component of a variety of research studies and public health efforts. Though numerous measurement tools are available to the researcher today, the accuracy with which many of these tools capture human movement behavior is unclear. Additionally, the relationships between commonly used measures of physical activity and sedentary behavior, as well as their associations with health outcomes, is not fully described. This is especially true among special population groups, including younger and older adults and clinical populations. It has become apparent that physical activity and sedentary behavior are multi-dimensional, complex, and interrelated behaviors [10], and as such, assessment of these activities requires careful selection of measurement tools. A one-size-fits-all approach should be utilized with caution; the ideal measurement protocol potentially differs by the population of interest, with age, gender, culture, clinical status, and occupation being some of the factors that may affect the types and patterns of a person's activities [29]. Most commonly, the goal of physical activity and sedentary behavior measurement is to determine their associations with health and wellness. Imprecise measurement of activity variables can lead to a diminution of the apparent effects of activity on health-related outcomes due to regression dilution bias [30]. Thus, a more sophisticated understanding of physical activity and sedentary behavior and their relations to various health aspects within different subpopulations is needed.

Fortunately, advancements in technology have increased the feasibility of objective, wearable device-based monitoring of human movement [31]. Specifically, pedometers and accelerometers are becoming more user-friendly and less expensive, with greater reliability and documented validity. Though these objective devices have greatly advanced the measurement field, there remain numerous important gaps in their capabilities. Commonly used objective measures such as accelerometers, while excellent at quantifying many forms of human movement, are unable to identify determinants of behaviors, may miss some behaviors that do not produce substantial changes in body acceleration but potentially have significant health effects (e.g. yoga), and cannot identify specific contexts or types of activities. Self-reported measures, though increasingly questioned for their usefulness among more technological tools, have many benefits and may help to fill these gaps [9, 31]. Schmidt et al. [32] found that a range of measurement tools may be needed to most accurately quantify associations between activity and health, due to their relative independence. Theoretically, a combination of objective and self-reported measures may yield the truest picture of a person's physical activity and sedentary behavior participation. Given the increased burden associated with multiple measures, however, the validity of this approach needs to be established before being utilized on a frequent basis [33].

Regardless of the approach taken, limitations in a tool's accuracy exist and should be minimized to the extent possible. The *Physical Activity Guidelines for Americans [7]* are founded in strong, significant, and consistent evidence including measured physical activity levels, but it is recognized that the measurement of physical activity, especially when self-reported, is subject to a relatively high degree of error [31]. Error associated with commonly used recall techniques are estimated to be between 35 and 50%, depending on age group or disease conditions [34]. The generally preferred objective measures of physical activity, such as accelerometers, present device selection, data interpretation, and data analysis challenges [34]. An accurate assessment of physical activity is crucial when it is to be used as an outcome, exposure, or confounding variable relating to health outcomes [10].

As with physical activity, the precise measurement of sedentary behavior is a prerequisite in establishing its true relationships with health outcomes and in the development of effective interventions. The measurement of sedentary behavior presents additional challenges, however. Recent evidence that sedentary behavior is both biologically and behaviorally distinct from physical activity indicates that researchers need to consider measures of both types of behavior to fully capture patterns of human movement [31]. Sedentary behavior's ubiquitous nature also poses reporting difficulties, with this behavior consuming more than half of a typical American's waking time [19]. The majority of the currently published literature utilizes screen time, self-report diaries, or accelerometer thresholds to indicate total sedentary behavior. The accuracy of the results of these studies remains uncertain due to inherent limitations of each method, however [35]. Contemporary environments demand or encourage sedentary behaviors and as such, this type of behavior has emerged as an important target for health promotion and obesity and disease prevention efforts [19, 20].

Therefore, a primary objective of this dissertation was to evaluate the validity of several commonly used field measures of physical activity and sedentary behavior among college freshmen using the criterion measure of the activPAL. Latent variables were also developed using components of each of the available measures to determine if a summary indicator of physical activity or sedentary behavior was more strongly related to the activPAL than the individual measures. Additionally, this study aimed to delineate the independent and any joint associations of the same commonly used measures of physical activity and sedentary behavior, with indicators of cardiometabolic health. The associations with indicators of cardiometabolic health were also examined in relation to the created latent variables. To achieve these objectives, two distinct, but related, studies were conducted. The specific aims of each study were as follows:

1.2 Specific Aims

Study 1:

Primary Aim: To explore the interrelationships between commonly used field measures of physical activity and sedentary behavior and determine their criterion-related validity with the activPAL activity monitor. It was hypothesized that 1) only weak associations (r <0.30) would be observed between alternative field measures of physical activity/sedentary behavior, 2) in separate multiple regression models, alternative field measures of physical activity/sedentary behavior would be independently associated with criterion estimates from the activPAL activity monitor, and 3) objective field measures of physical activity/sedentary behavior would be more strongly associated with activPAL estimates than subjective field measures.

Secondary Aim: To investigate if latent variables separately constructed for both sedentary behavior and physical activity were more strongly associated to the criterion measure of the activPAL than each of the independent measures. It was hypothesized that latent variables would be more strongly associated with activPAL estimates of physical activity and sedentary behavior than each of the component field measures.

Study 2:

Primary Aim: To examine the independent associations between physical activity and sedentary behavior with indicators of cardiometabolic health and determine if latent variables of these two behaviors improved upon the prediction as compared to the individual measures. It was hypothesized that 1) each field measure of physical activity and sedentary behavior would be associated with at least one of the cardiometabolic health indicators and 2) latent variables of physical activity and sedentary behavior would be better predictors of each cardiometabolic health indicator than their respective component measures.

Secondary Aim: To examine any interaction effects present between physical activity, sedentary behavior, and indicators of cardiometabolic health. It was hypothesized that associations between measures of physical activity and cardiometabolic health indicators would be stronger among those with higher levels of sedentary behavior versus those with lower levels.

Tertiary Aim: To determine if the associations between physical activity, sedentary behavior, and indicators of cardiometabolic risk varied based on DXA-measured body composition. It was hypothesized that associations between measures of physical activity/sedentary behavior and cardiometabolic health indicators would be stronger among those with higher body fat percentages versus those with lower levels.

1.3 Public Health Significance

As many public health campaigns turn towards the prevention of cardiometabolic diseases in an effort to reduce the disease burden and the rising associated financial implications, a complete understanding of modifiable risk factors, including physical activity and sedentary behavior, is essential. The measurement of physical activity and sedentary behavior is an invaluable yet currently imperfect science. A more thorough understanding of the relationships between available measures in addition to the independent and joint associations of these measures with actual health outcomes will help progress this important, and increasingly ubiquitous, field. College students represent a population at an important transitional point of life and thus may be an ideal population to target for primary prevention efforts. The results of this dissertation will aid in the selection of proper measurement tools for future studies, contributing to the existing body of research that directly compares subjective and objective measures of physical activity and sedentary behavior and their possibly independent relationships with health outcomes. The use of latent variables in this project will be beneficial towards determining if the use of multiple measurement tools is worth the additional burden.

1.4 Limitations

Limitations of this study included the cross-sectional design of the study, the self-reported wear times for the accelerometers, the wearing of accelerometer devices only during waking hours, and the use of an imperfect criterion measure.

1.5 Delimitations

The current study was delimited to subjects enrolled as first year, full-time students at the University of Georgia in Athens, Georgia during either the 2011-2012 or 2012-2013 school years. Subjects must have been between the age of 18 and 20 years, could not be varsity athletes, could not reside in on-campus housing, and could not be pregnant or attempting to become pregnant. Additionally, the findings of this study only apply to the select physical activity and sedentary behavior measures used in this study.

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CHAPTER 2

LITERATURE REVIEW

2.1 Physical Activity, Sedentary Behavior, and Health

Physical activity is defined as any type of bodily movement by the skeletal muscles requiring energy expenditure [1]. This behavior has been identified as an essential component of a healthy lifestyle [2]. The evidence supporting the health benefits of physical activity was strong, significant, and consistent enough to prompt the U.S. Department of Health and Humans Services to issue the *Physical Activity Guidelines for Americans* in 2008. The *Guidelines* recommend that adults participate in at least 150 minutes per week of moderate-intensity, or 75 minutes a week of vigorous-intensity, aerobic physical activity, and muscle-strengthening activities of moderate to high intensity for all major muscle groups on two or more days per week for substantial health benefits [3]. Despite the publication of these guidelines, many Americans fail to meet the physical activity recommendations. According to 2007 Behavioral Risk Factor Surveillance System and Center for Disease Control data, the percentage of adults who did not report meeting the existing guidelines ranged from 38.6% in Louisiana to 60.8% in Alaska. The mean percentage among states was 49.5% [4].

In addition to physical activity, more recent evidence has suggested that sedentary behavior is also an important modifiable health-related behavior. Sedentary behaviors, as defined by activities performed in the sitting, reclining, or lying position with an energy expenditure between 1.0 and 1.5 METS (multiples of the basal metabolic rate), are increasingly common in modern society [5]. Changes in transportation, communications, workplace, domestic, and leisure technologies have led to a significantly reduced demand for physical activity and increased opportunities for sitting [5]. Depending on the age of the adult, recent population-based accelerometer studies indicate that only 1% to 5% of the waking day is spent in moderate to vigorous physical activity of any kind and only 0.5% to 1% of this is sustained for at least 10 minutes [6]. This leaves a large portion of the day available for inactive and sedentary behaviors. Accelerometer data from over 6000 adult participants in the 2003-2006 U.S. National Health Nutrition Examination Survey (NHANES) found that mean accelerometer-derived sedentary time across 10-year age categories ranged between 7.3 and 9.3 hours per day; older adults tended to be the most sedentary [7, 8].

As it is apparent that physical inactivity and sedentary behavior are commonplace in the modern world, establishing the precise relationships between these behaviors and diverse health outcomes is crucial. Accurate measurement of the behaviors is an important step in this process, as is an understanding of the associations between these measures and health status among a wide range of population groups.

2.2 Measurement of Physical Activity

With the agreement that physical activity is beneficial towards health, it has become necessary to be able to accurately identify, assess, and track physical activity among individuals and populations in the field setting [9]. Improving the measurement of physical activity would lead to a better understanding of the dose-response relationship between the activity and numerous health outcomes. Additionally, the effectiveness of interventions and programs and secular behavioral trends could be more precisely monitored [10]. Though the measurement of physical activity has become relatively common, it remains an imperfect science with gaps in the literature and no true consensus on the best practices and techniques [10]. A multitude of methods exist for measuring physical activity in the field, each with its own benefits and shortcomings [11]. In general, physical activity measurement techniques can be divided into subjective and objective approaches.

Subjective Measurement of Physical Activity

Subjective tools, including activity diaries, recalls, and questionnaires are the most widely used, as they are capable of collecting data on a large sample at a relatively low cost [12]. Recalls and questionnaires do not alter the behavior being studied and are able to assess all the dimensions of physical activity so that patterns of behavior can be studied. They also can be used among a wide age range and can be adapted to fit the needs of a particular subject base or research question. Numerous limitations of subjective measurements do exist, however, and are significant [13]. Physical activity may be over reported due to social desirability bias [14]. Recalling past activities can also be cognitively demanding and thus not appropriate for some population groups, including children or very old adults. A misunderstanding of ambiguous terms, such as "moderate intensity", may also introduce a large amount of error [12]. Additionally, these measures are limited by the response rate and the respondent's ability and desire to follow directions [12]. Frequently used physical activity questionnaires that have been validated among diverse samples include the International Physical Activity Questionnaire (IPAQ) [15, 16] and the Godin Leisure Time Exercise Questionnaire [17]. In general, validity correlations for summary measures of adults' habitual or global physical activity are low, ranging from $r = 0.14$ to 0.36, most likely due to the inherent limitations of self-report as well as variable criterion measures. Subscales assessing vigorous activity tend to have greater correlation values than those measuring moderate physical activity [12], possibly due to the increased ability to recall the more intentional vigorous types of activities .

Objective Measurement of Physical Activity

Increasingly, the assessment of physical activity is turning towards wearable monitors to objectively quantify activity levels. Technological advancements and new data processing techniques have greatly progressed the field, providing the researcher with numerous valid and reliable devices to choose from. Challenges remain, however, especially in regards to how to best collect, calibrate, process and use data from wearable monitors [18]. Wearable activity monitors are grounded in the measurement of energy expenditure [19], with tools such as pedometers and accelerometers relying on quantifying the amount and/or intensity of motion to estimate energy expenditure.

Pedometers are small, lightweight wearable monitors best suited to count steps, though some models can also estimate distance covered and energy expenditure [19]. They operate through one of three mechanisms: a spring-suspended horizontal lever arm, a magnetic reed proximity switch, or a piezoelectric accelerometer [19]. Though pedometers may not be able to capture all forms of activity and can lead to reactivity (when subjects either intentionally or unintentionally increase their behavior of interest while they know it is being monitored), they are frequently regarded as a practical tool for both individual and population level uses due to their lower cost and feasibility of data collection and management [20]. Pedometer output also generally correlates highly with accelerometer counts [21]. The newer piezoelectric pedometers have the capability to store memory and respond to vertical accelerations while allowing some devices to quantify intensity of steps [20].

Accelerometers record motion in one or more planes and are capable of indicating the frequency, duration, and intensity of physical activity based on acceleration signals from a piezoelectric element. Validity studies with accelerometers have generally demonstrated moderate to strong correlations ($r = 0.45$ to 0.93) between accelerometer counts and oxygen consumption among adults, with similar correlations in children [19]. Accelerometers are frequently viewed as the preferred method for objective physical activity measurement and may be used as a criterion against which other measures are validated [10]. Though wearable devices provide a generally unobtrusive and valid measurement of physical activity, often across many days, they are not without their shortcomings. These monitors are often unable to capture all types of movement [19], such as overhead lifting or swimming, may not be able to provide information on the environment and context of the activity, may cause a subject to modify their normal activity patterns, and there are no standard wear time requirements [22, 23]. Additionally, they are frequently expensive and can produce large amounts of data requiring complex processing techniques [10].

Combination of Subjective and Objective Physical Activity Measurement

Despite a plethora of physical activity measurement tools available to today's researcher, few studies have directly compared the utility of a range of subjective and objective measures and their associations with health outcomes [16, 24]. Many population-based studies have focused on leisure time physical activity [25, 26], an approach that has been challenged by some with the argument that measuring total physical activity is most important when determining relationships with health outcomes [27, 28]. A study by Schmidt et al. [24] among a cohort of Australian young adults did not find this to be true, however, as IPAQ-based leisure time estimates were more strongly associated with cardiometabolic risk factors than total activity and associations between different measures of physical activity and cardiometabolic risk were fairly independent. This finding may differ among population subgroups where leisure time activity plays a less significant role. Another study reported that self-reported physical activity revealed only some of the relationships with health risk biomarkers and thus may underestimate the strength of any relationships [16]. It is feasible that a combination of both subjective and objective measures that each capture different facets of the behavior may yield the truest picture of one's physical activity but due to the increased researcher and subject burden, this approach should be confirmed before regular use. For example, Going et al. [29] used accelerometers to measure the dose of activity and a specifically designed 24-hour recall questionnaire to gain information on the frequency and types of activity among school children. Latent variables could be created from the data accumulated from multiple measures in order to aggregate the information provided from various measures into one summary measure. Also, as technology continues to advance, instruments are being developed that combine multiple elements of measurement into one device, such as motion sensors combined with heat sensors [30].

2.3 Measurement of Sedentary Behavior

Recent epidemiological and experimental studies on sedentary behavior provide a convincing case that this type of behavior may be an important independent component of the physical activity and health equation [8]. Much of the existing sedentary behavior research is based on subjective measures of the activity, which serves as a major limitation [31, 32]. These studies have generally assessed a specific representative activity, such as television viewing time or commuting time. Negative health outcomes, including self-reported weight change, obesity, type II diabetes, objectively measured cardiometabolic biomarkers, and raised mortality risk have been associated with television viewing time [33-38]. Commuting distance has been shown to be adversely associated with adiposity and indicators of metabolic risk in addition to cardiorespiratory fitness and physical activity [39]. Though television viewing and commuting distance are common sources of sedentary behavior, they may not accurately quantify sedentariness as they do not represent all aspects of sedentary behavior. Thus, many of the existing studies that make claims in regards to the negative health implications associated with sedentary behavior may not have actually measured the behavior [30]. Further exacerbating this limitation, in the earlier literature there was no consensus definition of sedentary behavior. Contrasting definitions of either actively engaging in sedentary behaviors versus the absence of moderately intense physical activity have created confusion as they relate to health outcomes in different ways [40]. A movement towards a common definition of sedentary behavior as being distinct from inactivity and advances in measurement technology are progressing the area of research and the ability to accurately measure sedentary behavior in the field setting.

Self-Reported Measurement of Sedentary Behavior

In addition to the problems noted above, sedentary behavior is complicated by its ubiquitous and sporadic nature. The proxy measures of television viewing or commuting distance have been used because providing an exhaustive listing of all possible sedentary activities is unrealistic [40]. Additionally, sedentary behavior frequently occurs in shorts bouts that may not be accurately recognized or recalled by self-report measures. The patterns of these bouts may have important health implications, however [41]. Clark et al. [42] assessed the validity of an interviewer-administered questionnaire used to measure workplace sitting time and breaks from sitting. Their results indicated a significant correlation between self-reported sitting time and accelerometer threshold-based sitting time ($r = 0.39$) but the authors cautioned that the precision of this approach may be limited.

Several commonly used physical activity questionnaires, including the IPAQ, have questions aimed specifically at identifying time spent in the sitting position. The IPAQ addresses sitting time on both weekdays and weekend days [15]. Among a cohort of 317 adults living in Chile without a history of cardiovascular disease, the mean IPAQ-reported sitting time was approximately 13% lower than accelerometer-derived sedentary time (454.2 versus 523.1 minutes/day). Regardless of measurement approach, increases in sitting time were associated with increases in risk factors (or decreases in protective factors), including insulin, glucose, blood pressure, blood lipids, and body composition. Analyses of the trends of this data, however, revealed that IPAQ-derived sedentary measures may lead to a decreased ability to detect real relationships with metabolic and vascular disease as compared to objective measures [16]. Other studies have revealed relatively modest correlations between the IPAQ sedentary measures and accelerometer-derived sedentary time ($r = 0.14 – 0.51$) [15, 43-45], emphasizing the need for more research utilizing objective measurement techniques and/or improved self-report methods.

Objective Measurement of Sedentary Behavior

Though more representative of inactivity than actual sedentary behavior, pedometer step counts below 5,000 steps per day have been suggested to be indicative of a sedentary lifestyle [10, 11, 46]. Schmidt et al. found that sedentary subjects (based on pedometer step counts) had the greatest prevalence of adverse cardiometabolic indicators in all groups except younger men. Those subjects in the low-active category (i.e. 5,000-7,499 steps per day) had a substantially lower prevalence [47]. A similar pattern has been shown between pedometer steps and body composition [13, 28, 48].

Accelerometers have been the most commonly used objective measure of sedentary behavior to date, relying on sedentary thresholds of activity counts to classify an activity as sedentary (e.g. less than or equal to 100 or 150 counts per minute) [40, 49]. Despite accelerometers being able to capture the short bouts and breaks in sedentary behavior throughout a wear period, the use of thresholds to determine the activity as opposed to direct postural measurement may be problematic. The data from accelerometers suggests "activity" which is inferred to be reflective of "behavior", however debate remains over the optimal cut points to be used as thresholds of sedentary behavior and light-intensity activity [49, 50]. Additionally, the best cut points may differ by the age, ethnicity, or adiposity status of the studied population [5]. The use of accelerometers in large population-based studies, including NHANES, has greatly progressed the current knowledge base on sedentary behavior while also illustrating the high prevalence of sedentary behavior among American adults [51].

The activPAL Professional Physical Activity Monitor (PAL Technologies Ltd., Glasgow, UK) is an inclinometer-based activity monitor that is worn on the midline of the thigh. The device enables researchers to directly identify periods of sitting/lying, standing, and stepping in addition to collecting data on ambulation [52] like other types of accelerometers. Because of the activPAL's unique approach to quantifying sedentary behavior, its use has been promoted for studies investigating sedentary behavior as a primary variable [5, 53]. The device's ability to measure static and dynamic activities in adults [45], posture during activities of free-living [54], step and cadence among females [55], and sedentary time among children [56], adolescent females [31], and adults [49] have all been validated. In comparison to two 6-hour periods of direct observation of overweight office workers, the activPAL underestimated sitting time by 2.8% and had a strong correlation with observed behavior ($r = 0.94$) [49]. Among a sample of 62 females aged 15-25 who participated in a standard treadmill protocol, no difference was seen between video recorded step count and the activPAL output. Additionally, the activPAL step function produced better results at slow walking speeds than the Actigraph accelerometer [55].

2.4 Cardiometabolic Disease

A substantial portion of the existing evidence on the health effects associated with physical activity and sedentary behavior centers on cardiometabolic health outcomes. Cardiometabolic diseases are by far the leading causes of morbidity and mortality in the United States, despite a four decade-long period of decline in age-standardized cardiovascular disease and stroke death rates [57]. Approximately half of the decline in mortality rates can be attributed to downward shifts in population levels of blood pressure, cholesterol, and smoking. The remaining decline is a result of implementation of effective treatment plans. Unfortunately, the national burden of cardiometabolic diseases remains high due to increases in the prevalence of obesity and diabetes, as well as an aging population [57]. Though most cardiometabolic diseases become apparent in adulthood, it has become clear that the atherosclerotic process originates in childhood and progresses throughout adolescence and young adulthood, before ultimately resulting in lesions that clinically manifest as coronary heart disease in middle-aged and older individuals [58]. The burden associated with cardiometabolic diseases is enormous, in terms of life-years lost, diminished quality of life, and both direct and indirect medical costs [57]. As markers of either potential future or current risk for cardiometabolic diseases, several outcomes are used, including various risk profile scores and a multitude of specific risk indicators.

Cardiometabolic Risk Profile

Multiple long-term, large population-based studies have demonstrated the power of maintaining a low risk profile into middle age on reducing one's risk for cardiovascular disease events and increasing longevity [59-62]. A risk profile typically consists of both modifiable and non-modifiable risk factors. Modifiable risk factors may include body mass index, alcohol intake, diet score, physical activity participation, smoking status, non-HDL cholesterol, HDL cholesterol, blood glucose, and blood pressure [62, 63]. Non-modifiable risk factors are age and gender [63]. Because of the recognition that the atherosclerotic process begins early in life, preceding the presence of signs and symptoms, these factors may be studied early in life. The presence of adverse levels of modifiable risk factors among young individuals have been shown to identify those at high risk for developing advanced atherosclerotic lesions [63-65]. A risk score, calculated from the presence (or absence) of the above risk factors, can estimate the probability of advanced atherosclerotic lesions in the coronary arteries and the abdominal aorta [63].

One such risk score, from the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) study, has been developed from cardiovascular disease risk factors found in relation to atherosclerotic lesions among a large sample of 15 to 34 year olds who died of external causes and underwent autopsies [63]. Risk scores were developed to estimate the probability of having advanced atherosclerotic lesions from traditional coronary heart disease risk factors, including age, gender, serum lipoprotein concentrations, smoking, hypertension, obesity, and hyperglycemia. The risk scores were normalized such that a one-unit increase was equivalent to a one-year increase in age. Odds ratios for a one-unit increase in risk score were 1.18 and 1.29 for lesions in the coronary arteries and abdominal aorta, respectively [63]. McMahan et al. found that the PDAY risk score also predicted coronary artery atherosclerosis in middle-aged adults up to age 54 years [66] as well as early atherosclerotic lesions among young people [58].

Cardiometabolic Health Indicators

In addition to risk profiles, several other outcomes are commonly used as indicators of cardiometabolic health status. Homeostasis model assessment (HOMA) is a method for assessing insulin sensitivity and beta-cell function from basal glucose and insulin concentrations [67]. It has been found to be an appropriate tool for use in cohort and cross-sectional studies and has the advantage of using only a single plasma sample assayed for insulin and glucose. The HOMA model has been compared favorably with many well-validated methods used to measure insulin resistance [67-69].

C-reactive protein (CRP) is an acute-phase reactant that is used to indicate the presence of systemic inflammation. Particularly, increased levels of high-sensitivity CRP (CRP) predict acute coronary events in both patients with known disease and apparently healthy subjects [70]. Serum CRP levels in children have been shown to be independently associated with advanced atherosclerosis after the age of 25 years [71], identifying it as a useful marker for screening children who are at risk for developing cardiovascular disease as an adult. The pathophysiology of atherosclerosis includes an inflammatory process and hence several prospective epidemiological studies have found CRP to be an independent predictor of cardiovascular events [1, 2, 72].

2.5 Cardiometabolic Risk, Physical Activity, and Sedentary Behavior

Physical Activity and Cardiometabolic Risk

A large body of research has accumulated over the past several decades supporting the notion that regular physical activity has beneficial effects on a variety of health risk factors and outcomes [73]. In the primary prevention of cardiovascular disease, the relative risk of all-cause death has been shown to be reduced by 20-35% among those with the highest levels of physical activity and fitness among both men and women [64, 67]. In a large prospective study, each 500 kilocalorie increase in weekly energy expenditure resulted in a 6% decreased incidence of type II diabetes, a result that was particularly evident among those at high risk for the disease [74]. Among women, a graded inverse relationship appears to be present between physical activity and the risk of cardiovascular-related death. In a meta-analysis of primary prevention efforts among women, the most active women had a relative risk of 0.67 compared to their least active counterparts. This protective effect was evident with as little as one hour of walking per week [75].

Additionally, physical activity is beneficial in the secondary prevention of cardiometabolic diseases [73]. A systematic review and meta-analysis of 48 clinical trials demonstrated that a cardiac rehabilitation program significantly reduced the risk of all-cause and cardiovascular disease-related premature death when compared to usual care [65]. Evidence suggests that a leisure-activity energy expenditure of approximately 1600 kcal per week can halt the progression of coronary artery disease [76] while patients with heart disease can increase their leisure-time energy expenditure to about 2200 kcal per week to reduce arterial plaque build-up [77]. Among a cohort of men (n = 1253, mean age of 50 years), type 2 diabetics who were also physically inactive had a 1.7-fold increased risk of premature death compared with those who were physically active, but also had type 2 diabetes [75].

Due in part to physical activity's ability to improve body composition, insulin sensitivity, lipid profiles, and coronary blood flow, as well as reduce systemic inflammation, blood pressure, and blood coagulation and produce positive changes in endothelial function, it has become clear that the beneficial effects of physical activity are irrefutable [73]. It is also evident that some physical activity is better than none and that a dose-response effect is present between dose and intensity of activity, especially with cardiometabolic-related outcomes [57].

Sedentary Behavior and Cardiometabolic Risk

The recent accumulation of evidence suggesting that prolonged and extensive sitting is a distinct risk factor for several health outcomes centers around biomarkers of diabetes risk, including obesity, two-hour plasma glucose, lipids, and abnormal glucose tolerance, as well as premature mortality, some forms of cancer, and cardiometabolic risk factors and profiles [8, 78]. Time spent in sedentary behavior has been consistently associated with an increased risk for all-cause, cardiovascular disease-related, and all-other-causes of mortality in both men and women, independent of body mass index and physical activity [78]. Analyses of NHANES data reported significant, detrimental, linear associations of total sedentary time with waist circumference, high-density lipoprotein lipase (HDL) cholesterol, C-reactive protein, triglycerides, insulin, and insulin sensitivity following adjustment for covariates, including exercise [79]. Additionally, among a large sample of Australian adults without known diabetes, self-reported television viewing time, a common surrogate measure for sitting time, was positively associated with undiagnosed abnormal glucose metabolism [80] and the metabolic syndrome [81]. These associations persisted following adjustment for waist circumference and moderate-intensity leisure-time physical activity [80-82].

More specifically, multiple large studies in Europe and Australia have demonstrated the consequences of high levels of sedentary behavior on cardiometabolic health outcomes, including the ProActive trial, the RISC study, and the AusDiab study [5]. The ProActive and RISC studies each found detrimental cross-sectional relationships between sedentary time and insulin, though this finding was of borderline significance in the one-year prospective analyses in the ProActive trial (258 participants aged 30-50 years with a family history type 2 diabetes) [83] and was attenuated with adjustment for total activity in the RISC study (801 healthy 30-60 year old participants) [84]. The accelerometer-based AusDiab study conducted among 11,000 Australian adults observed unfavorable associations of sedentary time with waist circumference, triglyceride levels, two-hour plasma glucose, and a clustered metabolic risk score [68, 85]. Using NHANES data from American adults, total sedentary time was associated with cardiometabolic biomarkers and CRP [79].

Additionally, in the Nurses' Health Study a total of 50, 277 women who were not obese at baseline were followed over a six-year period. Each two-hour per day increase in television viewing time was associated with a 23% increased risk of obesity, following adjustment for other lifestyle factors including diet and physical activity [34]. Television viewing has also been associated with an increased risk of type II diabetes [34, 35], acute coronary syndrome [69], metabolic syndrome [81, 83, 86, 87], abnormal glucose tolerance [80], and biomarkers of cardiometabolic risk [6, 81, 88]. Only a limited number of studies have examined the prospective relationships between objective measures of sedentary behavior and cardiometabolic health and these results have been mixed [40].

Though the evidence supports a unique paradigm of inactivity physiology, much remains to be understood mechanistically [82]. Studies among laboratory rats have thus far provided the most definitive experimental evidence. Preventing rats from standing or spontaneously walking resulted in a rapid and profound decrease in the concentration of HDL cholesterol on the first day of inactivity (22%) that persisted over many days [89]. Radioactive triglyceride tracers have been used to examine the metabolic effects of not utilizing postural support leg muscles. Results showed that these muscles quickly lost more than 75% of their ability to clear the fat circulating in the lipoproteins from the bloodstream when incidental contractile activity was reduced, a reduction that was related to a large loss of lipoprotein lipase activity locally [82, 88]. It has also been suggested that the loss of local muscle contraction, as occurs during prolonged sitting, may blunt the translocation of GLUT-4 glucose transporters to the skeletal muscle cell surface, thereby reducing glucose uptake [89, 90]. Increases in the circulating levels of glucose, triglycerides, and free fatty acids can generate excess free radicals, resulting in inflammation, endothelial dysfunction, hypercoagulability, and increased sympathetic activity. Sustained over a period of time, adverse cardiometabolic profiles may result [91]. Additionally, sedentary behavior may promote weight gain by replacing participation in light-intensity, incidental activity or by promoting increased energy intake, specifically through snacking behavior [78, 92, 93].

Regardless of the precise mechanism, accumulating evidence is generally consistent that sedentary behavior is an important health behavior with potentially detrimental cardiometabolic outcomes. A limited number of studies, especially those of longitudinal design, as well as some inconsistencies between findings, including after adjustment for covariates such as body composition, emphasize the need for further research in this area [78]. Although meeting the physical activity guidelines remains vital, this level of physical activity does not appear to be protective against excessive sedentary behavior [5] and the two behaviors would probably be best viewed as independent of one another.

2.6 Physical Activity, Sedentary Behavior, and Cardiometabolic Health among College Students

It has been well-documented that the transition from childhood to adulthood is marked by a sharp decline in physical activity [75, 94, 95]. Sedentary behaviors are also highly prevalent during this time [4, 51]. Given the evidence that many cardiometabolic diseases have their origins early in life and these diseases' associations with physical activity and sedentary behavior, primary prevention efforts are important for those at this transitory age. Existing research has most frequently studied the relationships between modifiable health behaviors, such as physical activity and sedentary behavior, and biomarkers of chronic disease risk among children or adults but has frequently neglected the young adult population [4, 96]. The college years traditionally occur during or near this transition point in life and thus college campuses may serve as a unique opportunity to examine chronic disease risk among a large number of young adults [96]. Young adults, including most college students, are in a period termed the "demographically dense years", during which many major changes in life may occur [97]. Hogan has demonstrated that the patterns attained during this period are more important than family background for ordering key events in the life cycle [6], and thus the establishment of sound health behaviors during this time is crucial.

2.7 Summary

The numerous positive health implications associated with physical activity, including in regards to cardiometabolic diseases, are well-documented. The field of physical activity measurement has made great progress with advancements in technology and data processing techniques, however the relationships between many of the commonly used measures and their associations with health outcomes are not fully elucidated. This holds especially true among subgroups of the population, such as young adults. Likewise, the negative health effects associated with sedentary behavior are becoming increasingly recognized yet much of the existing literature is limited by potentially poor measurement of the actual behavior. Overall the findings strongly suggest that sedentary behavior may have detrimental health effects however the evidence remains mixed among some outcomes and is not yet as conclusive as with physical activity. It is also not yet certain whether sedentary behavior is completely independent of physical activity participation. Differences may exist based on measurement approach as well as population of interest. Subjective and objective measures each have their benefits but neither approach is perfect. It is possible that a combination of complementary subjective and objective measures may yield the clearest picture of both physical activity and sedentary behavior, but this technique is not yet validated. Further research is needed to support this approach, as well as to better describe the relationships between commonly used measures and their associations with cardiometabolic health indicators.

Additionally, as the focus of healthcare turns to preventive medicine, it is logical to focus on encouraging the establishment and maintenance of healthy behaviors early in life. College students may represent a prime audience for these efforts. Thus, investigating the relationships between various measures of physical activity and sedentary behavior and their respective associations with cardiometabolic health indicators is warranted.

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CHAPTER 3

ASSOCIATIONS BETWEEN FIELD MEASURES OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR IN RELATION TO THE ACTIVPAL ACTIVITY MONITOR AMONG COLLEGE STUDENTS

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3.0 Abstract

Physical activity (PA) and sedentary behavior (SED) are important health-related behaviors. To fully elucidate their effects, precise measurement of the behaviors is essential. The ideal measurement approach is dependent upon numerous factors, including the study population and outcome(s). This study aimed to explore the interrelationships between subjective and objective measures of PA and SED and their associations with the activPAL criterion measure. This study also aimed to determine if latent variables constructed for each behavior would be more strongly associated with criterion measures than their components. The PA and SED of college students (n = 54, 18.4 ± 0.5 yrs, 62.7% female) was assessed with subjective measures including the Godin Leisure Time Questionnaire, the International Physical Activity Questionnaire (IPAQ), the Global Physical Activity Questionnaire (GPAQ), and a television viewing time question. Objective measures included the criterion measure of the activPAL and the New Lifestyles 1000 accelerometer. In general, weak to moderate relationships were found between the subjective and objective measures of PA and with the criterion (r = -0.08 to 0.49) though stronger correlations existed between the objective measures (r = 0.66 to 0.87). New Lifestyle's steps per day best predicted activPAL steps per day (R^2 = 0.76). ActivPAL mean aerobic steps per day were best predicted by the New Lifestyle's steps per day and activity minutes (R^2 = 0.69). Few subjective measures were independent predictors of PA but did not additionally contribute to the overall prediction. SED as measured by the activPAL was weakly predicted by negative associations with television viewing time and New Lifestyle's steps per day (R^2 = 0.12). Latent variables of PA and SED were not more strongly related to the criterion measures than their

respective component scores (r range = -0.02 to 0.80 for PA and -0.08 to 0.04 for SED). It is concluded that interrelationships do exist between commonly used measures of PA and SED among college students. However, the generally weak correlations with the activPAL suggest that self-reported measures should be used cautiously, especially for SED. Latent variables did not appear to improve upon the strength of the prediction of objectively measured activity.
Index words: physical activity, sedentary behavior, subjective measures, objective measures, activPAL, college students

3.1 Introduction

Evidence from a variety of research studies demonstrates that both a lack of physical activity (PA) and excessive sedentary behavior (SED) are associated with many adverse health outcomes and conditions, including but not limited to an increased risk of premature mortality, cardiovascular disease, metabolic syndrome, obesity, diabetes, cancer, and some mental health conditions [1-7]. Despite this knowledge, most American adults do not meet the recommended PA guidelines established by the United States Department of Health and Human Services and spend an estimated 51-68% of their total waking hours in sedentary pursuits [8, 9].

In order to accurately quantify the strength and nature of the relationships between these behaviors and health outcomes, precise measurement of PA and SED is critical, requiring careful consideration when selecting measurement tools [10, 11]. The validity of many commonly used tools remains unclear. Different techniques may correctly capture select components of these behaviors but fail to provide a complete quantification of a person's activity [10, 12, 13]. Correlations between self-reported measures of PA and SED and criterion accelerometer methods are often modest, ranging from $r = 0.05$ to 0.55 for PA and $r = 0.14$ to 0.51 for SED [14]. Imprecision in measurement, especially the potentially greater sources of error associated with subjective techniques, tends to reduce the strength of associations between these behaviors and health outcomes, potentially leading to spurious conclusions [15]. Furthermore, it is important that the accuracy of alternative measurement approaches be assessed across different population subgroups as age, gender, ethnicity, health status, and occupation may affect the types and patterns of a person's activities [10, 13].

Self-report measures are often used in population-based studies due to their economic and practical feasibility, and ability to characterize activities by their frequency, intensity, duration, and type [13, 16]. Although self-report measures are subject to several important sources of error, including low reliability [17, 18] and response bias [19], and can overlook unstructured activities, subjective tools remain a valuable component of measurement [20, 21]. Technological advances have increased the feasibility and reliability of objective measurement techniques, but the higher financial cost, significant subject and researcher burden, and inability to capture certain forms of activity, historical behaviors, and contextual information are considerable limitations.

Theoretically, the integration of information from several complementary tools, such as a self-report questionnaire and an objective accelerometer may yield a truer picture of a person's PA or SED participation. For example, a summary measure derived from several different tools may be a superior indicator of one's activity status compared to each of the individual measures [22]. Relatively few studies have created summary measures that combine objective and subjective PA measures. Among a group of 213 Belgian adolescents, a slightly stronger association between the IPAQ-Adolescents component scores and accelerometer counts was found when the accelerometer data was combined with a non-wear activity diary[23]. Bringolf-Isler et al. [24] combined accelerometers and a time activity diary to better describe the intensity and duration of specific activities among 189 school children. Given the increased burden associated with multiple measures, however, the validity of this approach needs to be established before it can be recommended for use.

It is evident that the measurement of PA and SED is an important yet imperfect endeavor. This study examined the interrelationships between commonly used field measures of physical activity and sedentary behavior and determined their criterion-related validity with the activPAL activity monitor among college students. The activPAL is an activity monitor capable of quantifying PA as well as being recognized as a gold standard measure of SED because of its objective measurement of movement, direct estimation of body inclination allowing it to not rely on thresholds or cut-points, and ability to detect changes in time spent in specific positions (i.e. sitting/lying, standing, and stepping) [25]. It was hypothesized that 1) only weak associations (r <0.30) would be observed between alternative field measures of PA/SED, 2) in separate multiple regression models, alternative field measures of PA/SED would be independently associated with criterion estimates from the activPAL activity monitor, and 3) objective field measures of PA/SED would be more strongly associated with activPAL estimates than subjective field measures. A secondary aim of this study was to investigate if latent variables separately constructed for both SED and PA were more strongly associated to the criterion measure of the activPAL than the independent measures.

3.2 Materials and Methods

Design and Participants

This project makes use of data from the Preventing Obesity With Education and Responsibility (POWER) Dawgs study, a cross-sectional, descriptive investigation conducted at the University of Georgia. Data were obtained in two waves during the year 2012.

Four-hundred and fifty-four subjects participated in the POWER Dawgs study. Approximately one in five of these subjects were randomly selected to wear a secondary measurement device (the activPAL) that made them eligible for inclusion in this sub-study. ActivPAL data was collected on sixty subjects (18.4 ± 0.5 years, range 18-19 years) and 54 subjects provided complete data for this portion of the study. Inclusion criteria included being a full-time, first-year student enrolled at the University of Georgia in Athens, Georgia, residing in on-campus housing, and not being a member of a varsity athletic team. Subjects were excluded if they were pregnant, planning to become pregnant, or had given birth in the previous 12 months. Subjects were recruited during the spring semester 2012 for wave 1 (n = 30) and during fall semester 2012 for wave 2 (n = 30). Recruitment took place through an email listserv of all freshmen students provided by the school's registrar's office, as well as fliers and advertisements in a school newspaper. Following screening, all participants completed a university Institutional Review Board approved informed consent prior to participation in the study.

Procedure

Prior to scheduling in-person visits, an online screening questionnaire was completed. Eligible participants were then scheduled for two appointments. During the first visit, subjects completed an informed consent and were provided with two accelerometer devices (the New Lifestyles 1000 and the activPAL), accelerometer record of use forms for each device, and a checklist of all study requirements. During the eight days between visit 1 and visit 2, subjects were asked to wear the accelerometers daily as well as complete all required questionnaires electronically via Survey Monkey, an online questionnaire tool. Visit two included review of accelerometer and questionnaire records as well as anthropometric measurements.

Measures of Physical Activity

Subjective Measures

PA was determined with several techniques including the long form of the International Physical Activity Questionnaire (IPAQ). The IPAQ was used to provide estimates of physical activity during the past week. Summary measures from the IPAQ included in the analyses for this study include domain-specific total PA at work, in active transport, domestic work, and leisure time; total PA for walking, moderate, and vigorous intensities; and a total PA score in metabolic equivalent (MET)-minutes per week. Subjects were asked to report activities of moderate- or vigorous-intensity that they participated in for at least ten minutes in duration. The IPAQ is an internationally recognized survey for use in adults 18 to 65 years of age. Its measurement properties show good levels of repeatability and moderate validity when compared to accelerometer data; findings that are typical of other comparisons between objectively measured and self-report measures of PA [26].

Subjects also completed the Godin Leisure Time Exercise Questionnaire [27]. This four item questionnaire is used to assess typical weekly leisure time PA. Questions are intensity-specific, including light, moderate, and vigorous activity, and require a minimum of 15 minute bouts to be included. A summary total leisure activity score is also calculated. Moderate to strong test-retest reliability has been demonstrated among healthy adults and adolescents. Generally good validity has been established between the Godin and subjective and objective measures of PA among adult populations [13, 27].

The Global Physical Activity Questionnaire (GPAQ) was also administered to assess PA participation over a typical week. Subjects were instructed to include only those activities of at least 10 minutes in duration. Indicators used in these analyses were total recreational activity, total travel activity, and total minutes and METs of activity per week. The GPAQ was developed by the World Health Organization for PA surveillance in countries and has been shown to have a moderate-strong positive correlation with the IPAQ and acceptable to good reliability [28, 29]. The GPAQ is weakly related to accelerometer counts [28, 30].

Objective Measures

PA was also measured with several objective techniques. Subjects wore the New Lifestyles 1000 accelerometer (piezoelectric pedometer) at the waist over the midline of their right thigh via a belt clip during all waking hours for seven consecutive days. A record of use log was provided to each subject along with verbal and written instructions to record their times of wear, step count, and activity minutes at the end of each day. The data on the record of use form was verified from the accelerometer recordings by the research team on the subject's second visit. The researcher noted the values stored in the accelerometer's seven-day memory and compared these to the values recorded by the subject. In case of discrepancy, the values recorded from the device's memory were used. The threshold for activity inclusion into the activity minute count was set at 4 on a 1 to 9 scale, which is estimated to be equal to an intensity level of 3.6 METS (NewLifestyles User Guide, 2005, NewLifestyles Inc., Lee's Summit, Missouri). Outcomes used for these analyses included steps per day and moderate to vigorous activity minutes per day. Piezoelectric pedometers have been shown to accurately quantify increasing walking intensity activities (< 2% error) and be more sensitive to walking behavior than other pedometers [31].

A subset of subjects also concomitantly wore the activPAL activity monitor (PAL Technologies Ltd, Glasgow, Scotland), which was used as the criterion measure for this study. The activPAL was worn during all waking hours on the anterior aspect of the right thigh and was attached using a sticky gel pad and medical-grade tape. A record of use form was provided to the subject to record times of wear and any time periods of non-wear. The activPAL records step number, instantaneous cadence for each period of walking, and identifies episodes of walking, sitting/lying, and standing in real time. It has been shown to be a reliable (interclass correlation ≥ 0.99) and valid (absolute error < 1.11%) measure of walking across multiple speeds among adults, when evaluated against video observation [32].

Measures of Sedentary Behavior

Subjective Measures

SED was assessed via many of the same methodologies as PA. The IPAQ asks participants to estimate their total time spent seated on a typical weekday and weekend day. Correlations between total IPAQ-derived sitting time and accelerometer counts <100/minute have been shown to be meaningful but modest among a sample of 289 adults (r = 0.33) [33].The GPAQ assesses time spent sitting or reclining on a typical day. As a portion of the Health History Questionnaire used in this study, subjects were also asked to report the typical number of hours per day they spend watching television. Television viewing time has frequently been used as an indicator of sedentary time [34, 35].

Objective Measures

SED was also assessed objectively. The New Lifestyles 1000 accelerometer captured steps, which has been used to classify individuals as ‘sedentary’, with a daily step count of less than 5000 steps being a commonly accepted threshold for sedentary classification among adults [36]. The activPAL was used as the criterion measure of SED, as it is the current gold standard approach for the measurement of this type of behavior [37].The activPAL recorded positional data such that episodes of sitting and lying down could be distinguished from other activities. Total time per day spent in the seated or lying position was calculated to determine SED.

Data Processing

Subjective Measures

The Godin Leisure Time Exercise Questionnaire, the IPAQ, and the GPAQ were all scored according to their respective standard data cleaning and scoring rubrics. Reported values deemed unfeasible (e.g. summed to greater than 24 hours for one day) were excluded from analyses. Values of less than the minimum duration required for inclusion by the respective questionnaire were re-coded to ‘zero’. For the IPAQ and GPAQ, to ensure responses were entered in the correct time column, ‘hour’ values of ‘15’, ‘30’, ‘45’, ‘60’, and ‘90’ were converted to minutes. The IPAQ assesses sitting time separately for weekend days and weekdays. In order to create an indicator of total weekly sitting time, a weighted average was calculated ((mean weekday sitting hours * # of weekdays/total days) + (mean weekend sitting hours * # of weekend days/total days)).

Objective Measures

For both the New Lifestyles 1000 accelerometer and the activPAL activity monitor, a minimum of four days (three weekdays and one weekend day) of valid data were required for inclusion in analyses. A valid day was considered a minimum of 10 hours of wear [38]. Minimum wear time requirements calculated with the 70/80 rule [39] produced results similar to the 10-hour threshold used in this study. Days with inadequate wear time and/or a step count less than 500 were set to missing values. ActivPAL self-reported wear hours were visually confirmed with the activPAL output to ensure that the wear times reported approximated those times with activity measured. Time spent sitting, standing, and stepping were calculated as the total time spent during wear hours in each of these activities. Subjects were asked to wear the activPAL during all waking hours. However, because the activPAL was not worn for 24 hours per day, activity patterns were potentially not captured during non-wear times while subjects were awake, such as at the beginning and end of each day. As this time was most likely spent sedentary, an adjusted version of sitting time was created to crudely correct for any potential bias. The adjusted sitting time was equal to: mean sitting time + ((24 hours – typical sleep time) – mean self-report wear hours). Typical sleep time was obtained from the results of the Pittsburgh Sleep Quality Index [40] questionnaire that was administered as part of this study. ActivPAL aerobic steps was calculated as an index of moderate-vigorous ambulatory activity and equivalent to the number of steps per day taken at or above a cadence of 100 steps/minute, a threshold previously shown to correspond with at least moderate-intensity activity in adults [41].

Statistical Analyses

Data were analyzed using STATA (version 12; Statacorp, TX). A normal distribution pattern was assessed for all variables and non-normality was addressed with an appropriate transformation. In order to describe the population, demographic variables are presented as means ± standard deviation (SD) for continuous variables and percentages for categorical variables. Spearman correlations were used to assess the bivariable associations between alternative subjective and objective measures of both PA and SED. Based on our sample size of 54 subjects, this study was powered at 0.80 to detect correlations of $r = 0.33$, similar to the magnitude of effect shown to be meaningful in prior studies.

To determine the independent predictors of the criterion estimates, independent variables were considered eligible to be entered into the model based on a statistically significant ($p < 0.25$ to qualify for entry in initial regression models) bivariable correlation with the outcome of interest. A forward stepwise approach was then used to select variables for inclusion and retention in final multivariable regression models. ActivPAL step count per day and aerobic step count per day were selected as outcomes to represent both the amount and intensity of PA and activPAL sitting time was used as the outcome to indicate SED. A log-transformed aerobic step count per day was used to better approximate a normal distribution. With all outcomes, subjective independent variables were first entered into the models, followed by objective measures added in separately to the best subjective model ("separate models"). Standardized beta coefficients were also calculated to facilitate comparison of the strength of the different independent predictors in each model. Initial alpha levels were set at 0.20 for entry and

0.25 to return. Final models required a $p \leq 0.05$ for retention. Full models were computed with all components of the separate models for the respective outcome. Post-regression diagnostic checks were run on all final models, including residual plots to verify the assumption of homoscedasticity. All models approximated this assumption, following the log transformation of the aerobic step outcome. The DFBETA statistic was used to detect subjects having disproportionate influence on regression models. Any observation with a DFBETA outside of the 1.00 cutoff [42] was dropped from analyses, as was the case with one participant with regards to television viewing time.

To create latent variables to serve as summary measures for both PA and SED, factor analysis with a principal-component factor approach was employed, followed by a varimax rotation. Coefficient values from factors with an Eigenvalue greater than 1.0 were retained to create the new summary variables. Latent variables were created from the total self-reported and non-activPAL objective measures as well as using only the subjective measures. This approach was taken in order to have a set of latent variables without the effects of the objective measures that may closely align with the outcomes. Spearman correlations were used to assess the bivariable associations between the latent variables and the criterion estimates of PA and SED. Significantly correlated ($p < 0.25$) latent variables were eligible for entry into forward stepwise multivariable regression models developed to compare the strength of the associations between the latent variables and the criterion measures against the independent field measures with the criterions. Final regression models required $p \leq 0.05$ for retention of predictors. Finally, the final models of latent variables were compared with the final models from the individual components.

3.3 Results

Subject demographic information, PA characteristics, and SED characteristics are summarized in tables 3.1 - 3.3. Participants were primarily female (62.7%) with an average body mass index of 23.2 ± 3.4. The sample was 64.4% white, 11.9% black, 17% Asian, and 6.8% Hispanic. In general, the population was active, averaging over 10,000 steps per day (10176 ± 2471), and self-reported most of their activity coming from travel and recreational activities, especially those involving walking. Despite the relatively high step counts among this sample, SED was also prevalent, averaging 10.1 ± 1.1 hours per day. Substantial underestimation of self-reported SED was apparent, on average about four hours per day.

Associations between Measures of Physical Activity and Sedentary Behavior

The interrelationships between the measures of PA are presented in table 3.4 (total summary measures) and table 3.5 (objective versus subjective domain measures). Among objective measures, correlations were generally strong within and between the activPAL and the New Lifestyles 1000 accelerometer output (r range = 0.66 to 0.87, all $p < 0.01$). Spearman correlations between the PA criterion outcomes from the activPAL, including both mean steps per day and aerobic steps per day, were moderate for total activity estimates from the Godin (r range = 0.29 to 0.35, both $p < 0.05$) and the IPAQ (r range = 0.29 to 0.44, both $p < 0.05$). The criterion outcomes were also moderately correlated with Godin vigorous activity (r range = 0.44 to 0.49, both $p < 0.05$) and IPAQ vigorous activity (r range = 0.33 to 0.40, both $p < 0.05$). ActivPAL steps per day were also moderately associated with IPAQ walking ($r = 0.38$, $p < 0.01$) and total travel estimates ($r = 0.32$, $p < 0.05$) but were more modestly correlated with IPAQ-based estimates of recreational activity ($r = 0.28$, $p < 0.05$). Aerobic steps, derived from the activPAL as a surrogate of moderate-vigorous intensity activity, were more strongly associated with Godin moderate intensity activity than steps per day ($r = 0.24$ versus $r = 0.18$) but had lower, but significant, correlations with IPAQ walking ($r = 0.29$, $p < 0.05$ versus $r = 0.38$, $p < 0.01$) and IPAQ total travel ($r = 0.28$, $p < 0.05$ versus $r = 0.32$, $p < 0.05$). Estimates of activity from the GPAQ were not significantly correlated with any of the objective measures (r range = 0.06 to 0.26, all $p > 0.05$). The associations between the New Lifestyles 1000 accelerometer variables and the self-reported estimates were similar to those of the activPAL.

Spearman correlations between subjective and objective estimates of SED were generally weak to moderate in magnitude (Table 3.6) (r range = -0.27 to 0.10). ActivPAL-derived SED was not significantly correlated with any of the self-reported estimates or accelerometer-based steps. An adjusted activPAL sitting time measure was modestly negatively associated with New Lifestyles 1000 accelerometer steps per day ($r = -0.27$, $p < 0.05$) and television viewing time ($r = -0.27$, $p < 0.05$). Of note, the association with television viewing time was in the opposite direction than expected. The IPAQ and GPAQ-derived sitting time estimates were strongly associated with one another ($r = 0.73$, $p < 0.01$). Weekday and weekend day sitting time estimates were also compared between the activPAL and the IPAQ. Estimates from weekend days were weakly but significantly correlated ($r = 0.27$, $p < 0.05$) though the same was not true on weekdays ($r = -0.06$).

Independent Predictors of Criterion Estimates of Physical Activity and Sedentary Behavior

The independent contribution of alternative measures of PA in predicting activPAL measured PA was evaluated with multiple regression models (Table 3.7). Variables were selected for entry into the model based on the strength of their correlation with the respective outcome and their relative independence in estimating one or more sub-component of PA. For each outcome, separate models were first created for both self-report and objective field measures. These variables were then forced into a single prediction model ("Full Model") to examine their continued contribution to the prediction of each criterion measure. For both activPAL steps per day and activPAL aerobic steps per day, objective activity estimates from the New Lifestyles 1000 contributed most strongly to their prediction, explaining 76% of the total variance in steps and 66% of the total variance with aerobic steps. The self-report measures were relatively poor predictors of activPAL-measured activity. In models containing only self-reported measures, Godin total vigorous activity and IPAQ total travel activity were effective predictors of mean steps per day (model $R^2 = 0.25$, $p < 0.001$) and total activity from the Godin was a significant predictor of aerobic steps per day (model $R^2 = 0.18$, $p < 0.01$). When these predictors were included in a full model with objective measures, however, they did not increase the amount of variance explained by the objective predictors alone.

The β coefficients from the regression analyses for predictors of activPAL sedentary time are presented in table 3.8. As no self-report measures were correlated with mean unadjusted sitting time, a separate model could not be run for self-reported predictors. New Lifestyles 1000 accelerometer steps were an independent predictor of sitting time (model $R^2 = 0.07$, $p < 0.05$), with an inverse relationship as was expected. Separate self-report and objective measure models were also run for the adjusted sitting time outcome. Television viewing time was again unexpectedly negatively associated with adjusted sitting time. A combination of self-reported television viewing time and New Lifestyles steps per day significantly, but weakly, predicted adjusted sitting time (model $R^2 = 0.14$, $p < 0.05$).

Latent Summary Variables of Physical Activity and Sedentary Behavior

Factor analysis was used to create latent summary variables of PA and SED. Two separate models were used for both PA and SED. The first model included all self-reported domain-specific measures, followed by a second model that included any non-activPAL objective measures in conjunction with total scores from the different subjective tools. Tables 3.9 and 3.10 contain the factor analysis results for PA. For PA, two factors were created, one loading on the self-reported IPAQ and GPAQ measures and the second loading on objective measures. Four separate factors remained for the subjective-only model, including one loaded on lifestyle-type light and moderate activity, a second loaded on recreational vigorous activity, a third loading on work activity, and the final including light and moderate exercise. Several of these factors were significantly associated with the activPAL criterion outcomes (Table 3.11), with the cumulative factor loaded on objective measures representing the strongest associations (r range = 0.76 to 0.80, both $p < 0.01$). Overall, the factors from subjective-only measures were more weakly associated with the criterion outcomes; however the correlations between the lifestyle light/moderate activity with each of the outcomes and recreation/vigorous activity again with each of the outcomes were significant ($p < 0.05$).

Two cumulative factors and one subjective-only factor were created for SED (Tables 3.12 and 3.13). The cumulative factors loaded on self-report sitting time and on activities. The subjective-only factor loaded on self-reported sitting time. The associations between these factors and the activPAL-measured SED were very weak (r range = -0.08 to 0.04, $p > 0.05$) (Table 3.14). Regression analyses between the latent variables and the criterion measures were statistically significant for both PA measures (model $R^2 = 0.66$, $p < 0.001$ for each outcome) but no regression model could be created for SED (Table 3.15). The explained variability in each of the outcomes was not greater between models with latent variables than in those containing only the field measures. A regression model combining the final latent variable model with the final full model of field measures did not improve upon explained variance.

3.4 Discussion

The major findings from this study are that 1) in general, relationships of a weak to moderate magnitude were found between commonly used field measures of PA and SED, including with the criterion measure of the activPAL, 2) associations between field measures and the criterion measure were stronger among PA estimates than those for SED, 3) objective measures of PA and SED were better independent predictors of criterion estimates than subjective measures, and 4) latent variables constructed for PA and SED were not more strongly associated with the criterion measures than the individual measures. These findings indicate that several commonly used measures of PA and SED may not be appropriate for quantifying participation in these behaviors among a college student population. Additionally, although the combination of subjective and objective measurement approaches used in this study does provide additional insight into the characteristics of the behaviors, it does not appear to improve upon the ability to predict actual activity levels over the best individual measures. The results of this study confirm that the measurement of PA and SED is a challenge and that measurement approaches should be selected with the specific study population and outcomes in mind [15, 22, 43].

Interrelationships between Measures of PA and SED

Self-reported measures of PA and SED are often the most feasible approach due to their low-cost and convenience, however they have significant limitations [21, 30]. This leads many to use them as a complement to objective tools, such as accelerometers [30]. Studies involving SED, especially, have historically relied on self-report measures [14]. Prior research has estimated an error rate of between 35 and 50% associated with self-reported recall measures in comparison to objective measures [44]. Validity coefficients of a weak to moderate magnitude between self-report measures of both PA and SED and an objective criterion measure have generally been reported among adults [21, 33].

In concordance with these findings, the results from the current study also found weak to moderate correlations between subjective and objective measures of total PA. Relationships among the Godin, IPAQ, and GPAQ were similar to one another, but the associations between the objective measures of PA were stronger. Specifically, the leisure activity-focused Godin Leisure Time Exercise Questionnaire was more strongly associated with objective indicators of moderate-vigorous intensity activity while the comprehensive IPAQ was more closely aligned with total step counts, representative of total activity. The GPAQ was not significantly correlated with any of the objective measures of PA. This suggests that the Godin or IPAQ may be preferable for use among college students over the GPAQ and the selection between these two measures may depend on the study outcome. The IPAQ addresses activities over the past week as opposed to the typical week included in the GPAQ. As the current time frame of the IPAQ coincided more closely with the time period captured by the accelerometers, this may have been a benefit. The Godin also estimates a typical week of activity, but the leisure-type activities, focused primarily on sport and exercise activities, included in this survey may be more regular and memorable to college students than the variety of activities included in the GPAQ and IPAQ. Among the specific PA indices, self-reported estimates of vigorous activity were most strongly related to objective estimates, a finding supported by previous studies [45]. The IPAQ-assessed walking and travel activity were also significantly related to criterion estimates, most likely reflective of the high levels of ambulatory commuting that takes place on a residential college campus.

In regards to SED, only weak correlations were found between self-reported and objectively measured estimates. The study population substantially underestimated their daily sitting time in comparison to the criterion measure, by approximately 40% on average, and reported very low levels of television viewing time (0.9 ± 1.1 hours per day). The correlations between self-reported and subjectively measured SED in this study were lower than those reported in other studies. A systematic review of the objective-criterion related validity of PA questionnaires reported a median Spearman correlation value of r = 0.23 among the SED components, compared to the r = -0.06 to 0.04 found in this study [30]. College students may have an especially difficult time accurately self-reporting their SED due to the large amount of variability in their daily schedule, the sporadic nature of their sitting bouts (e.g. commuting on a bus across campus, visiting with friends in their dorm rooms), and their interpretation of a television-viewing question.

Independent predictors of criterion-estimates of PA and SED

While the relationships between the Godin, IPAQ, and GPAQ have previously been examined in relation to different objective criterions, this study is the first to attempt to determine how these measures independently predict PA and SED in college students. Our findings indicate that there were several independent predictors of both behaviors. Contrary to our hypothesis, however, the objective measures were not consistently more strongly associated with activPAL criterion measures than the subjective measures. The self-reported Godin total vigorous activity and the IPAQ total travel activity were independent predictors of activPAL steps per day, as was the objective New Lifestyles accelerometer's steps per day. A full model including all three of these independent predictors (Godin vigorous activity, IPAQ travel activity, and accelerometer steps) did not improve upon the association with the activPAL seen with the accelerometer steps alone. The combination of the measures resulted in the self-reported measures becoming non-significant, indicating that the objective measure was the strongest predictor. The Godin total activity estimate was an effective predictor of activPAL aerobic steps per day, in addition to the New Lifestyle's steps and activity steps. Again, when both subjective and objective measures were combined, the prediction was not improved over that with the objective measures alone. These findings indicate that the simple, single-domain Godin questionnaire performed better than the comprehensive and more intensive

IPAQ in predicting activPAL-measured PA in this study, though it was inferior to the objective measures from the New Lifestyles accelerometers.

Few measures were independently associated with SED measured with the gold standard method, the activPAL. An unexpected negative association was found between television viewing time and sitting time, adjusted for typical sleeping time. A significant negative coefficient was also evident for New Lifestyles accelerometer steps per day, as was expected. The two variables did have a slight additive effect on the predictive ability of one another. The objective measure was not more strongly associated with the criterion measure than the self-report, as was hypothesized. Television viewing time has frequently been used as a surrogate measure of SED with greater viewing times associated with greater SED [46]. The findings of this study suggest a different relationship where greater SED was associated with less viewing time. In relation to the large amounts of SED measured by the activPAL in this study, it is likely that the actual television viewing time was substantially underreported or was a poor surrogate measure of total screen time. A possible explanation for this paradoxical finding is that the specific television viewing question used in this study was not appropriate for the given population. The college student population engages in a wide variety of screen-based activities and actual television watching may represent only a small portion of this type of behavior. Future studies among a similar demographic group may consider inquiring about all seated screen-based entertainment instead of only that specifically watched on a television.

Latent Variables of Physical Activity and Sedentary Behavior

A novel aspect of the current study was the creation of latent variables from the non-criterion field measures of PA and SED. Previous studies have assessed these behaviors through multiple approaches. However, the different measures have typically been used as a complement to a primary technique (e.g. addition of non-wear time activity diary to accelerometer data) [23] or to confirm data findings (e.g. when a questionnaire is used in a large sample with accelerometer data collected in a sub-group) [47]. Theoretically, the creation of summary variables from multiple measures of PA or SED would take advantage of the unique contributions of each tool and reduce the dimensionality of numerous measures. It was hypothesized that these summary latent variables would be more strongly associated with criterion estimates than each of the component field measures. However, our findings did not support this hypothesis. Latent variables were created from subjective field measures alone, and from a combination of subjective and objective field measures of both PA and SED. These variables were created separately so that the influences of the subjective measures alone could be identified and not blurred by the impact of the objective measures that most closely aligned with the outcome measures. The PA latent variables that favored lifestyle-type light to moderate activity, recreational/vigorous activity, objective measures, and the IPAQ and GPAQ total activity were significantly associated with activPAL steps and aerobic steps. None of the associations were stronger than those found with the comparable field measures alone, aside from a slight improvement with the latent variable loaded on objective measures and activPAL aerobic steps. SED latent variables loaded on self-report sitting time and on activities (i.e. steps and television viewing) and were only very weakly associated with sitting time from the activPAL, similar to the individual measures. The combination of subjective and objective measurement approaches in this study does aid in more fully describing the PA and SED characteristics of college students, however in relation to a measure of absolute total activity or sitting time, the individual measures, especially from objective tools, appears sufficient. The current study supports the common belief that a preference be placed on objective measures [44] and that subjective tools may serve as an informative complement [21, 22].

Limitations and Conclusions

Although the current study utilized an objective measure of PA and a gold-standard measure of SED, and explored these behaviors through a novel approach, the study is not without limitations. The study population was representative of typical college students in many demographic aspects, however subjects did volunteer for participation in this study with the knowledge that there were health-related outcomes, and thus may have more desirable health-related behavior habits than those of the average college student. Also, the activPAL and the New Lifestyles accelerometer were only worn during waking hours and subjects self-reported their wear times. The use of the activPAL as a criterion measure has its own limitations. The output from the activPAL device does not provide a readily available measure of intensity that can be directly compared to the MET-minutes estimated by the self-reported tools. The activPAL also does not capture all activities that college students may participate in, including upper body movements or those involving water such as swimming. In comparison to the New Lifestyles 1000 accelerometer, the differences in device placement and measuring mechanism of the activPAL allows for a smaller degree of error in measurement. Activities that are common among college students and are addressed with many self-report tools, such as riding a bicycle, may be missed by a New Lifestyles accelerometer but could be captured with the activPAL. Finally, although the IPAQ and GPAQ are used in the literature to assess SED, no questionnaires specific to SED or screen time habits were used in this study. Future work should consider 24-hour wear of the activPAL and incorporating more specific subjective measures of SED to better describe the characteristics of this behavior.

In conclusion, the current study contributes several important findings to the body of measurement research. First, the PA and SED habits of college students, a unique population, were described from multiple approaches. Next, though objective measures are preferred, it is recommended that PA questionnaires including inquires of active travel and vigorous recreational activities should be selected for the most accurate estimates. The IPAQ and Godin Leisure Time Exercise Questionnaire both have acceptable associations with an objective criterion measure, similar to those found in the existing literature among other population groups [30]. Additionally, due to the weak correlations observed in this study, caution should be used when considering self-reported estimates of SED. Finally, the creation of summary variables from multiple measures of PA and SED does not appear to provide additional benefit in determining total activity time or sitting time. Due to the established relationships between PA, SED, and a multitude of health outcomes, an important next step is to determine the applicability of these findings in relation to predicting future health risk.

3.5 References

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Table 3.1 Participant demographics

Characteristic	n	Mean ± SD/%	Range
Age (years)	60	18.4 ± 0.5	18 - 19
Ethnicity	59		
White		64.4%	
Black		11.9%	
Asian		17.0%	
Hispanic		6.8%	
Gender (% female)	59	62.7%	
BMI (kg/m^2)	59	23.2 ± 3.4	16.9 - 37.4
Adiposity (% fat)	59	28.4 ± 8.7	12.8 - 45.6

SD = standard deviation; BMI = body mass index

Table 3.2 Summary of physical activity participation by measure

Measure	n	Mean ± SD	Range
activPAL			
Steps/day	60	10176.5 ± 2471.4	4745.1 - 15925.7
Aerobic steps/day	60	7164.8 ± 2177	3125.2 - 14337.1
Wear time[a,c]	60	14.3 ± 1.1	12.0 - 16.7
New Lifestyles 1000			
Steps/day	58	10608.8 ± 2452.6	5599.3 - 16237.1
Activity time[a]	57	0.8 ± 0.3	0.2 - 1.6
Godin Leisure Time			
Total activity	57	50 ± 30	0 - 110
Mild activity	59	12.1 ± 11.1	0 - 45
Moderate activity	58	17.7 ± 17.9	0 - 80
Vigorous activity	58	21.7 ± 18.5	0 - 90
IPAQ			
Total activity[b]	60	4594.3 ± 3459.7	396 - 16860
Walking activity[b]	60	2157.5 ± 1821.0	49.5 - 7722.0
Moderate activity[b]	60	1404.4 ± 1594.0	0 - 6330
Vigorous activity[b]	60	1197.3 ± 2005.8	0 - 12000
Work activity[b]	60	674.8 ± 2479.1	0 - 16800
Travel activity[b]	60	1883.9 ± 1658.0	49.5 - 7623.0
Domestic activity[b]	60	720.6 ± 1024.7	0 - 5400
Recreation activity[b]	60	1540.0 ± 1826.2	0 - 7119
GPAQ			
Total activity[b]	60	5942.2 ± 4513.4	0 - 18016
Work activity[a]	60	0.9 ± 1.1	0 - 4.2
Travel activity[a]	60	1.3 ± 1.5	0 - 8.6
Recreation activity[a]	60	0.9 ± 1.0	0 - 3.6

IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; SD = standard deviation

[a]Hours per day; [b]MET-minutes per week; [c]Self-reported

Note: Godin measured in arbitrary units

Table 3.3 Summary of sedentary behavior participation by measure

Measure	n	Mean ± SD	Range
Television viewing time (hours/day)	59	0.9 ± 1.1	0 - 4
activPAL			
Sitting time (hours/day)	60	10.1 ± 1.1	7.1 - 12.9
Sitting time adjusted[a] (hours/day)	59	13.2 ± 1.4	9.3 - 16.3
IPAQ			
Total sitting, weighted avg (hours/day)	59	6.1 ± 2.6	1.9 - 13.9
Weekday sitting time (hours/day)	60	6.0 ± 2.6	2.0 - 13.0
Weekend sitting time (hours/day)	59	6.2 ± 3.2	1.5 - 16.0
GPAQ			
Sitting time (hours/day)	60	5.7 ± 2.7	0.5 - 16.0

IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; SD = standard deviation

[a]Adjusted for typical sleeping time

Table 3.4 Spearman correlations between objective and subjective summary measures of physical activity, (n=54)

	activPAL steps/d	activPAL aerobic steps/d	NL-1000 steps/d[a]	NL-1000 activity minutes/d[a]	Godin total activity	IPAQ total met-min/wk
activPAL aerobic steps/d	0.84**	--	--	--	--	--
NL-1000 steps/d[a]	0.87**	0.76**	--	--	--	--
NL-1000 activity minutes/d[a]	0.66**	0.77**	0.80**	--	--	--
Godin total activity	0.29*	0.35**	0.36**	0.35**	--	--
IPAQ total met-min/wk[b]	0.44**	0.29*	0.44**	0.22	0.42**	--
GPAQ total met-min/wk[c]	0.21	0.17	0.19	0.17	0.28*	0.40**

*Significant correlation at $p < 0.05$; **Significant correlation at $p < 0.01$

[a]New-Lifestyles 1000 accelerometer; [b]International Physical Activity Questionnaire-Long; [c]Global Physical Activity Questionnaire

Table 3.5 Spearman correlations between subjective domain and objective measures of physical activity, (n=54)

	activPAL steps/d	activPAL aerobic steps/d	NL-1000 steps/d[a]	NL-1000 activity minutes/d[a]
Godin total activity	0.29*	0.35**	0.36**	0.35*
Godin light activity	-0.08	0.07	0.04	0.12
Godin moderate activity	0.18	0.24	0.26	0.25
Godin vigorous activity	0.49**	0.41**	0.46**	0.33*
IPAQ total met-min/wk[b]	0.44**	0.29*	0.44**	0.22
IPAQ walk[b]	0.38**	0.29*	0.38**	0.25
IPAQ moderate[b]	0.12	0.02	0.14	-0.03
IPAQ vigorous[b]	0.40**	0.33*	0.38**	0.36**
IPAQ recreation[b]	0.28*	0.24	0.24	0.17
IPAQ domestic[b]	0.11	0.07	0.09	0.01
IPAQ travel[b]	0.32*	0.28*	0.32*	0.26
IPAQ work[b]	0.07	-0.02	0.10	0.11
GPAQ total met-min/wk[c]	0.21	0.17	0.19	0.17
GPAQ recreation[c]	0.16	0.15	0.12	0.16
GPAQ travel[c]	0.20	0.23	0.26	0.21
GPAQ work[c]	0.06	0.08	0.11	0.12

*Significant correlation at $p < 0.05$; **Significant correlation at $p < 0.01$
[a]New-Lifestyles 1000 accelerometer; [b]International Physical Activity Questionnaire-Long; [c]Global Physical Activity Questionnaire

Table 3.6 Correlations between subjective and objective measures of sedentary behavior (hours/day), (n = 55)

	activPAL sit time adj[a]	NL-1000 steps/day[b]	IPAQ sit time[c,d]	GPAQ sit time[e]	TV time[f]
activPAL sit time	0.57**	-0.20	0.05	0.07	-0.22
activPAL sit time adj[a]	--	-0.27*	-0.06	0.04	-0.27*
NL-1000 steps/day[b]	--	--	0.06	-0.08	-0.01
IPAQ sit time[c,d]	--	--	--	0.73**	-0.15
GPAQ sit time[e]	--	--	--	--	-0.05

*Significant correlation at $p < 0.05$; **Significant corelation at $p < 0.01$

[a]Adjusted for typical sleep hours; [b]New-Lifestyles 1000 accelerometer; [c]International Physical Activity Questionnaire; [d]Weighted average of sedentary time across week; [e]Global Physical Activity Questionnaire; [f]Television viewing time

Table 3.7 Predictors of activPAL physical activity

	activPAL Steps/Day			
	Separate Models		**Full Model**	
Variable	Std β	*p*	Std β	*p*
Self-Report				
Godin vigorous	1029.63	0.001	238.30	0.193
IPAQ travel	633.66	0.030	283.44	0.092
Model R^2	0.25	<0.001		
Objective Measure				
NL-1000 mean steps/d	2129.97	<0.001	1900.45	<0.001
Model R^2	0.76	<0.001	0.76	<0.001
	activPAL Aerobic Steps/Day[a]			
	Separate Models		**Full Model**	
Variable	Std β	*p*	Std β	*p*
Self-Report				
Godin total activity	0.13	<0.001	0.040	0.136
Model R^2	0.18	0.009		
Objective Measure				
NL-1000 mean activity minutes/d	0.15	<0.001	0.16	0.001
NL-1000 mean steps/d	0.11	0.010	0.08	0.079
Model R^2	0.66	<0.001	0.66	<0.001

Multivariate regression model with forward stepwise selection; separate models include only self-report or objective measures; alpha set at $p \leq 0.05$ for inclusion in final models; full models include all separate model components.

Std β- regression coefficients with the x-variables in standard deviations and the y-variable in its original units

[a]Log transformed outcome

IPAQ = International Physical Activity Questionnaire; NL = New Lifestyles 1000 accelerometer

Table 3.8 Predictors of activPAL sedentary time

	activPAL Sitting Time			
	Separate Models		**Full Model**	
Variable	Std β	*p*	Std β	*p*
Self-Report				
None retained	--	--	--	--
Objective Measure				
NL-1000 mean steps/d	-0.29	0.049	-0.29	0.049
Model R^2	0.07	0.049	0.07	0.049
	activPAL Sitting Time, adjusted[a]			
	Separate Models		**Full Model**	
	Std β	*p*	Std β	*p*
Self-Report				
Television viewing hrs/d	-0.45	0.016	-0.34	0.045
Model R^2	0.10	0.016		
Objective Measure				
NL-1000 mean steps/d	-0.36	0.037	-0.34	0.048
Model R^2	0.08	0.037	0.14	0.017

Multivariate regression model with forward stepwise selection; separate models include only self-report or objective measures; alpha set at $p \leq 0.05$ for inclusion in final models; full models include all separate model components.

Std β- regression coefficients with the x-variables in standard deviations and the y-variable in its original units

[a]Adjusted for typical sleeping time

NL= New Lifestyles accelerometer

Table 3.9 Summary factor loadings with physical activity subjective predictors, (n=54)

Measure	1- Lifestyle light/moderate activity	2- Recreation/ vigorous activity	3- Work activity	4- Light/moderate exercise
Godin light	0.08	0.10	0.03	0.80*
Godin moderate	0.02	0.00	0.09	0.83*
Godin vigorous	0.00	0.87	0.10	-0.03
IPAQ walk	0.84*	0.12	-0.03	0.13
IPAQ moderate	0.70*	-0.02	0.39*	0.10
IPAQ vigorous	-0.06	0.64*	0.68*	-0.04
IPAQ work	0.07	-0.03	0.93*	0.09
IPAQ travel	0.86*	-0.06	0.04	-0.09
IPAQdomestic	0.73*	0.04	-0.15	0.20
IPAQ recreation	0.09	0.86*	-0.15	0.05
GPAQ work	0.07	-0.15	0.72*	0.05
GPAQ travel	0.63*	0.16	0.15	-0.17
GPAQ recreation	0.08	0.71*	-0.03	0.19
Explained variance	0.22	0.19	0.16	0.11

*Heavy loading variable

Table 3.10 Summary factor loadings with physical activity total subjective and objective predictors , (n=54)

Measure	1- Objective measures	2- IPAQ/GPAQ measures
NL-1000 steps	0.93*	0.15
NL-1000 activity minutes	0.93*	-0.01
Godin total activity	0.50	-0.01
IPAQ total MET-min	0.15	0.82*
GPAQ total MET-min	-0.01	0.82*
Explained variance	0.40	0.32

*Heavy loading variable

NL = New Lifestyles accelerometer; IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; MET = metabolic equivalent

Table 3.11 Correlations between physical activity latent variables and criterion estimates, (n=54)

	activPAL steps/d	activPAL aerobic steps/d
Cumulative factor 1[a] Objective measures	0.76**	0.80**
Cumulative factor 2[a] IPAQ/GPAQ measures	0.22	0.10
Subjective factor 1[b] Lifestyle light/moderate activity	0.31*	0.27*
Subjective factor 2[b] Recreation/vigorous activity	0.34*	0.31*
Subjective factor 3[b] Work activity	0.16	0.15
Subjective factor 4[b] Light/moderate exercise	-0.02	0.09

*Significant correlation at p < 0.05; ** Significant correlation at p < 0.01

[a]Total subjective and objective predictors; [b]Subjective-only predictors

IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire

Table 3.12 Summary factor loadings with sedentary time subjective predictors, (n=58)

Measure	1- Self-report sitting time
IPAQ sitting time/d	0.94*
GPAQ sitting time/d	0.93*
TV viewing hrs/d	-0.18
Explained variance	0.59

*Heavy loading variable

IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; TV = television; NL = New Lifestyles

Table 3.13 Summary factor loadings with sedentary time subjective and objective predictors, (n=56)

Measure	1- Self-report sitting time	2- Activities
IPAQ sitting time/d	0.94*	0.11
GPAQ sitting time/d	0.89*	0.33
TV viewing hrs/d	-0.28	0.62*
NL-1000 steps/d	0.31	-0.71*
Explained variance	0.46	0.25

*Heavy loading variable

IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; TV = television; NL = New Lifestyles

Table 3.14 Correlations between sedentary behavior latent variables and criterion estimates, (n=55, 56[a])

Measure	activPAL sit time	activPAL sit time adj[a]
Cumulative factor 1[b]	0.04	-0.02
Self-report sitting time		
Cumulative factor 2[b]	-0.08	-0.02
Activities		
Subjective factor 1[c]	0.04	-0.06
Self-report sitting time		

[a]Adjusted for typical sleep time; [b]Total subjective and objective predictors; [c]Subjective-only predictors

Table 3.15 Latent variable predictors of activPAL physical activity and sedentary behavior

Factor	β	*p*
Physical Activity		
activPAL Steps/Day		
Cumulative factor 1	1876.44	<0.001
Subjective factor 1	464.20	0.023
Model R^2	0.64	<0.001
activPAL Aerobic Steps/Day[a]		
Cumulative factor 1	0.24	<0.001
Model R^2	0.64	<0.001
Sedentary Behavior		
No factors retained in model	--	--

Multivariate regression model with forward stepwise selection; factors eligible for inclusion with Spearman correlation $p \leq 0.25$; alpha set at $p \leq 0.05$ for retention in regression models

[a]Log transformed outcome

CF1 = loaded on objective PA measures; SF1 = loaded on lifestyle light/moderate activity

CHAPTER 4

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR IN RELATION TO RISK FOR CARDIOMETABOLIC DISEASE IN COLLEGE STUDENTS

[2]Lucas, J. M., Schmidt, M.D., Das, B.M., Evans, E.M. To be submitted to *Journal of American College Health*.

4.0 Abstract

Though many cardiometabolic diseases have their origins early in life, the practice of certain health behaviors, including physical activity (PA) and sedentary behavior (SED), has been shown to assist in the prevention of such disease. The relationships between many commonly used measures of PA and SED and cardiometabolic outcomes remains unclear. This study aimed to delineate the associations between different measures of PA and SED with cardiometabolic health among college students, how these behaviors may interact, and to examine how these associations might vary by body composition. College students (n = 402, 18.3 yrs, 68.7% female) provided both subjective and objective measures of PA and SED through the Godin Leisure Time Questionnaire, the IPAQ, a television viewing question, and the wear of a New Lifestyles 1000 accelerometer (NL). Cardiometabolic risk was indicated by the homeostatic assessment of insulin resistance (HOMA), high-sensitivity C-reactive protein (CRP), the Pathobiological Determinants of Atherosclerosis in Youth risk score, and DXA-measured android body fat (BF%). BF% was independently associated with NL steps and Godin total activity for PA measures and NL steps for SED measures (model $R^2 = 0.35$ and 0.34, respectively). Adjusted for gender, the top quartile of activity from NL steps and Godin total activity was associated with a 50% reduction in prevalence of being at risk for an elevated HOMA level (all $p < 0.10$) compared to the lowest quarter. The top quartile of television watching was associated with a 91% increase in risk of a high CRP level compared with the lowest quartile ($p = 0.05$). Multivariate logistic regression analyses resulted in no multiple measure models for any of the outcomes. Latent variables were not better predictors of a high level of an outcome compared to individual

measures. No interaction effects were seen between high and low levels of PA on measures of SED and vice versa. No interaction effect was seen between PA/SED by BF%. We conclude that few measures of PA and SED are independently associated with cardiometabolic risk indicators in college students, and that latent variables did not improve upon the prediction of risk.
Index words: physical activity, sedentary behavior, cardiometabolic risk, measurement, college students

4.1 Introduction

The primary and secondary prevention of cardiometabolic disease is a focus of many current public health efforts [1], due to the enormous burden they present on society. Fortunately, it is suggested that prevention may be aided by the practice of certain modifiable behaviors, including adequate moderate and vigorous intensity physical activity (PA) and minimal sedentary behavior (SED) [2-4]. PA and SED have been shown to be relatively independent of one another, requiring that both behaviors are considered as components of the health equation [5].

The origins of many cardiometabolic diseases and conditions may be rooted early in life [1]. Fatty streaks and clinically significant raised lesions have been shown to increase rapidly in prevalence and extent during the 15- to 34-year age span [6]. Adverse levels of risk factors in the young adult years results in substantial elevations in long-term and lifetime risks for cardiometabolic diseases that are largely unavoidable [1]. Numerous indicators have shown promise in identifying young people at an increased risk of cardiometabolic disease later in life. These indicators include: risk scores calculated from traditional risk factors, including the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) [7], indicators of metabolic health such as the Homeostatic Model Assessment (HOMA) [8], markers of inflammation, such as C-reactive protein (CRP) [9, 10], and abdominal adiposity (android BF%) [11]. Additionally, PA and SED patterns during childhood, adolescence, and young adulthood are associated with subclinical cardiometabolic disease [4, 12, 13]. The transition from adolescence to young adulthood is traditionally a stage marked by a decline in PA participation, 24% on average, [8, 14-17] and pervasive SED [18]. The health-related behaviors of young adulthood are often maintained later into life [1, 19, 20], potentially further influencing cardiometabolic health [4].

The measurement of PA and SED is an evolving field. It is not yet clear which commonly used measures of these behaviors are most strongly associated with cardiometabolic outcomes [21], especially among many understudied populations. Numerous subjective and objective approaches are available, each with positive and negative attributes [22]. Utilizing the optimal tool(s) is essential to accurately identify and quantify relationships as well as characterize dose response patterns, both necessary steps in supporting and refining physical activity recommendations [21]. To overcome the limitations of individual measures, summary variables derived from several different complementary measures may improve the ability to examine relationships between PA, SED, and indicators of cardiometabolic health. Associations between various subjective and objective measures of PA and cardiometabolic risk have been found to be relatively independent, thus a combination of measures may be needed to most accurately describe the relationships between these behaviors and health [22, 23].

Further, the relationships between PA, SED, and cardiometabolic health indicators may be modified by body fat percentage (BF%). Body composition is either directly or indirectly related to most indicators of cardiometabolic health in addition to being associated with both PA and SED. Adults with high SED and low PA have a 95-168% increased odds of being obese [24]. While a higher BF% is known to be associated with greater risk for cardiometabolic diseases, the extent that BF% influences the relationships between PA, SED, and cardiometabolic health indicators is not clear. Some studies have concluded that PA is an independent predictor of risk while others suggest body composition attenuates or eliminates these relationships.

It is evident that relationships exist between PA, SED, and cardiometabolic health; however it is unclear how these associations may vary by measure of PA and SED. Therefore, the primary aim of the current study was to examine the independent associations between alternative measures of PA and SED with indicators of cardiometabolic health and determine if latent summary variables of these two behaviors improved the prediction as compared to the individual measures. It was hypothesized that 1) each field measure of PA and SED would be associated with at least one of the cardiometabolic health indicators and 2) latent variables of PA and SED would be better predictors of each cardiometabolic health indicator than their respective component measures. A secondary aim of this study was to examine any interaction effects present between PA, SED, and indicators of cardiometabolic health, with the hypothesis that associations between measures of PA and cardiometabolic health indicators would be stronger among those with higher levels of SED versus those with lower levels. An additional secondary aim was to determine if the associations between PA, SED, and indicators of cardiometabolic risk vary based on DXA-measured body composition. It was hypothesized that associations between measures of PA/SED and cardiometabolic health indicators would be stronger among those with higher android BF% versus those with lower levels.

4.2 Materials and Methods

Design and Participants

Data from the Preventing Obesity with Education and Responsibility (POWER) Dawgs study, a cross-sectional, descriptive investigation conducted at the University of Georgia, was used for this study. Four-hundred and fifty four subjects participated in the study. Fifty-two subjects were excluded from the current analyses due to incomplete data. Thus, four-hundred and two subjects (18.3 ± 0.5 years, 68.7% female) provided data for this study. All subjects were full-time, first-year student enrolled at the University of Georgia in Athens, Georgia, resided in on-campus housing, and were not a member of a varsity athletic team. Participants could also not be pregnant, planning to become pregnant, or have given birth in the previous 12 months. Subjects were recruited in two waves during 2012, wave 1 during the spring semester (n = 213) and wave 2 during the following fall semester (n = 189). Subjects were recruited through an email listserv of all freshmen students provided by the school's registrar's office, fliers, and advertisements in a school newspaper. Following screening, all participants completed a university Institutional Review Board approved informed consent prior to participation in the study.

Procedure

Preceding the scheduling of in-person visits, an online screening questionnaire was completed by all prospective subjects. Eligible participants were then scheduled for two appointments, slated eight days apart from one another. Visit 1 included completion of an informed consent document, a 15 mL venous fasting blood sample drawn by certified phlebotomists, and the subject was provided with an accelerometer,

accelerometer record of use form, and a checklist of all study requirements. During the eight days between visit 1 and visit 2, subjects were asked to wear the accelerometer during all waking hours, as well as complete all required questionnaires and diet records. Questionnaires were completed via Survey Monkey, an online questionnaire tool, and could be completed at the subject's convenience, though subjects were instructed to spread out completion of the questionnaires across multiple sessions. Visit 2 included review of accelerometer and questionnaire records with a trained team member as well as anthropometric measurements and a dual-energy x-ray absorptiometry (DXA) scan. Demographic variables including gender, ethnicity, age, and current smoking status were assessed by written self-report.

Cardiometabolic Measures

Blood pressure and heart rate

A digital blood pressure cuff (Omron, Kyoto, Japan) was used to obtain resting seated systolic and diastolic blood pressure. Measures were obtained on the right arm with the feet flat on the floor and the arm supported at heart level. The mean of the two readings that were within 10mmHg of each other were used in analyses. A resting heart rate reading was also taken at the same time, via the blood pressure cuff.

Blood measures and outcomes

Blood samples were collected via a 21G vacutainer needle into two serum-separating tubes of 7.5 mL each. Plasma glucose, high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol, and triglycerides were measured using spectrophotometry. Plasma insulin levels were measured with immunoassay. High-sensitivity C-reactive protein (CRP) was analyzed using laser nephelometry. All biochemical analyses were performed by a certified lab (Quest Diagnostics).

For this study, the homeostasis model assessment (HOMA) was used as an indicator of insulin resistance and beta cell function. The formula for calculating insulin resistance equals: ((FPI x FPG)/405), where FPI equals fasting plasma insulin (IU/mL) and FPG equals fasting plasma glucose (mg/dL). An overall cardiometabolic risk score was calculated using a formula from the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) study [7, 25]. This formula utilizes coronary heart disease risk factors to predict the probability of advanced atherosclerosis among persons 15-34 years of age. The risk score was calculated by tallying points based on values of the following risk factors: gender, age, serum lipoprotein concentrations, hypertension, hyperglycemia, obesity, and smoking status. Risk scores are normalized so that a 1-unit increase is equivalent to the multiplicative change in the odds because of a 1-year increase in age. A table detailing the PDAY scoring system is included in appendix 1.

Body Composition

Body weight was measured to the nearest 0.1 kg using a digital scale (Tanita, model WB-110A, Tokyo, Japan) while subjects wore a light layer of clothing without shoes. Height was also measured shoeless to the nearest 0.1 cm using a digital stadiometer (Seca, model 222, Hanover, MD). Body mass index was calculated as body mass (kilograms) divided by height (meters) squared (kg/m^2). Body composition, including whole body and regional soft tissue, was determined with a total body DXA scan according to standard procedures (iDXA, GE Healthcare-Luna, Madison, WI). All scans were analyzed in duplicate by the same two technicians. Fat mass was expressed as a percentage (%) of total body mass and of the android region (android BF%), including from the bottom of the ribs to the top of the iliac crests.

Measures of Physical Activity

Subjective Measures

The long form of the International Physical Activity questionnaire (IPAQ) was used to provide estimates of physical activity over the past week. Summary measures from the IPAQ includes domain-specific and overall estimates of walking, moderate, vigorous, and total physical activity. Domain-specific scores are provided for work, active transport, domestic, and leisure time activity. Subjects were asked to report activities that they participated in for at least ten minutes at a time. The IPAQ is an internationally recognized instrument developed for use in adults aged 18 to 65 years of age. Its measurement properties have been assessed in at least 12 countries, with good levels of repeatability and moderate validity when compared to accelerometer data, typical of other comparisons between objectively measured and self-report measures of physical activity [26].

Subjects also completed the Godin Leisure Time Exercise Questionnaire [27]. This four item questionnaire is intensity-specific and is used to assess typical weekly leisure time physical activity. A minimum of 15 minute bouts are required for inclusion. Summary measures available from this questionnaire include a total leisure activity score. Test-retest reliability has been demonstrated among healthy adults and school-age children and adolescents. Weak to moderate validity has been established between the Godin and measures of fitness, body composition, and other subjective and objective measures of physical activity among adult populations [27, 28].

Objective Measures

Physical activity was measured objectively using the New Lifestyles 1000 accelerometer (piezoelectric pedometer), worn at the waist over the midline of the subject's right thigh via belt clip for seven consecutive days. A record of use log was provided to each subject along with verbal and written instructions to record their hours of wear, step count, and activity minutes at the end of each day. The data on the record of use form was verified from the accelerometer's memory function by the research team on the subject's second visit. In case of discrepancy, the values recorded from the device's memory were used. The threshold for activity inclusion into the activity minute count was set at 4 on a 1 to 9 scale, which is estimated to be equal to 3.6 METS (NewLifestyles User Guide, 2005, NewLifestyles Inc., Lee's Summit, Missouri). Measures provided by the New Lifestyles monitor include steps per day and activity minutes per day.

Measures of Sedentary Behavior

Sedentary behavior was assessed the IPAQ-long's questions asking respondents to separately estimate their total time spent seated on a typical weekday and weekend day. Daily time spent watching television, a common surrogate measure of sedentary behavior, was assessed as part of the study's Health History Questionnaire.

Latent Variables

Latent variables were created to serve as a summary of the different measures of PA separately for females and males. An attempt was made to generate latent variables for SED, however, no significant or meaningful factors were generated. Factor analysis with a principal component factor approach and varimax rotation was applied to normalized (or approximately normalized) scores from all non-activPAL PA measures, separately for each gender. Principal components that represented large fractions of PA variance, with an Eigenvalue ≥ 1.0, were retained. For females, four components and their respective explained variances included: 1) light to moderate lifestyle activity (39%), 2) recreational and vigorous activity (18%), 3) mild to moderate exercise, and 4) objectively measured activity (9%). Among male subjects, five components and their respective explained variances included: 1) recreational and vigorous activity (32%), 2) work and travel activity (16%), 3) mild to moderate exercise (14%), 4) moderate lifestyle domestic activity (11%), and 5) objectively measured activity (7%). From the separate principal component factors, a mean score representing total physical activity was computed by summing the individual factors, each weighted for its relative contribution of the explained variance. For females, the total PA score was 0 ± 0.45, and for males, the total PA score was 0 ± 0.41.

Data Processing

Subjective Measures of PA/SED

Standard data cleaning and scoring rubrics were used for the Godin [28] and the IPAQ [29]. Responses of "I prefer not to answer this question" and those that fell outside of a feasible range (e.g. total time summed to greater than 24 hours for a day's activities or less than the required bout duration) were excluded from analyses. A weighted average (mean weekday hours * # of weekdays/total days + mean weekend hours * # of weekend days/total days) of total weekly sitting time was created from the IPAQ's two sitting time estimates, one for weekdays and one for weekend days.

Objective Measures of PA

Wear time requirements for the New Lifestyles 1000 accelerometer were set at a minimum of 4 days (one weekend day and three weekdays). A minimum of 10 hours of wear constituted a valid day [30]. Minimum wear day requirements calculated with the commonly used 70/80 rule produced results similar to the 10-hour threshold used for this study [31]. A threshold of 500 steps per day was required for the inclusion of that day in analyses.

Statistical Analyses

Data were analyzed using STATA (version 12; Statacorp, TX). Descriptive analyses were performed for all variables separately by gender and as a total group. Tests for normal distribution were completed on all variables and non-normal variables were appropriately transformed, where possible, to approximate a normal distribution pattern. In order to describe the population, demographic variables are presented as means ± standard deviation (SD), medians, 25th, and 75th percentiles for continuous variables and percentages for categorical variables. Unpaired t-tests, Wilcoxon rank-sum tests, and chi-square tests were used to determine any differences in the means of the normally distributed continuous variables and the medians of the non-normally distributed continuous variables and the categorical variables, respectively, across genders. Due to the differences observed between genders in these analyses and its role as a potential confounder, remaining analyses were performed following either adjustment for, or stratification by, gender. Based on a total sample size of 402 subjects, the study was adequately powered (0.99) to detect meaningful correlations between physical activity and cardiometabolic measures, defined as those with 5% or more shared variance (i.e., r =

0.22). In gender stratified analyses, the power to detect meaningful correlations of r = 0.22 was 0.98 among females and 0.81 among males.

Spearman correlations were used to determine the relationships between PA and SED measures with each of the outcomes, HOMA, CRP, PDAY, and android BF%, by gender. The associations between the latent variables of PA and the cardiometabolic health outcomes were also assessed with Spearman correlations. Gender and android BF% percentage were identified as potential confounders and controlled for in analyses with either adjustment or stratification.

As the only normally distributed outcome, multiple linear regression with a forward stepwise model building approach was used to identify significant PA and SED predictors of android BF%. An alpha level of $p \leq 0.10$ was used for inclusion in the final models. Standard scores of each of the objective and self-reported total activity measures were used to allow comparison between measures of different units and transformations. All models were adjusted for gender and interaction effects between gender and each measure were investigated with likelihood ratio tests.

Categorical measures of PA and SED objective and subjective total activity scores were created with gender-specific quartile cut-point values. The cut-point approach was used because many of the measures could not be normalized. Exceeding the gender-specific 85th percentile for a given outcome was used as the threshold to indicate elevated risk, given the limited number of subjects with clinically elevated outcome levels. The gender-specific threshold values included: HOMA females > 1.3, males ≥ 1.1, CRP females ≥ 2.7, males ≥ 2.5, and PDAY females > 0, males ≥ 2. For the remaining cardiometabolic outcomes (HOMA, CRP, and PDAY), logistic regression was used to produce gender-adjusted prevalence odds ratios and Score chi-square trend values for all categorical measures. Forward stepwise logistic regression (initial pr = 0.25, pe = 0.20) was used to evaluate the best multiple measure model for each of the outcomes, however no such models were significant.

A comparison of the predictive ability of the models containing the total PA latent variables against the individual field measures was performed with the C-statistic. Receiver operator characteristic (ROC) area was compared between a logistic regression model including the total PA factor score and the objective/total measures available for the respective behavior separately for each gender. These analyses were repeated for each of the binary outcomes, HOMA, CRP, and PDAY.

Interaction effects were assessed with a dichotomous (median split) categorical variable of the potential interacting variable. To determine any interaction effects present between high and low levels of SED in the relationship between measures of PA and indicators of cardiometabolic risk, the dichotomous variable was created from the IPAQ sitting time estimate. A PA indicator variable was created from the New Lifestyles 1000 accelerometer's mean step count to determine any effect modification among SED and the risk outcomes. Finally, to assess if body composition modified the associations between PA/SED and cardiometabolic risk, a dichotomous variable of DXA-measured android BF% was produced with a gender-specific median split. Likelihood ratio tests were used to assess the overall significance of interaction terms.

4.3 Results

Subject demographics are presented in table 4.1. Participants were primarily white females. Males and females statistically differed in height, weight, total and android BF%, total cholesterol, HDL cholesterol, blood glucose, insulin, C-reactive protein, resting systolic blood pressure, resting heart rate, current smoking status, and PDAY risk score. Summary measures of PA and SED are described in table 4.2. Overall, participants were active and reported the majority of their PA coming from travel and recreation-type activities. Males self-reported greater total, vigorous, and recreation activities than females. In general, subjects reported little television viewing and below average sitting time. Approximately 7% of the original study sample (n = 432) that completed both study visits was excluded from analyses on the basis of inadequate or implausible PA and SED data. Participants missing this information did not differ from those included in the analyses in terms of demographic variables or cardiometabolic risk outcomes (Appendices 2 - 3).

Associations between measures of PA and SED with cardiometabolic outcomes

Table 4.3 displays the interrelationships between measures of PA and SED with cardiometabolic outcomes by gender. The associations were weak in magnitude across genders and outcomes. The relationships were generally stronger in females than males and tended to be most strongly associated with android BF% in females and HOMA in males. Among females, HOMA and CRP were also significantly associated with multiple measures of PA. In females, the objective measures from the New Lifestyles 1000 accelerometer (step count and activity minutes) were most consistently associated with cardiometabolic outcomes but the same was not true among males. IPAQ recreation activity was the most highly associated measure in males. Unexpectedly, several positive (but not statistically significant, aside from IPAQ moderate) correlations were found between PA measures and cardiometabolic risk, especially with female’s CRP and

PDAY. Self-reported time spent viewing television was significantly associated with several cardiometabolic risk indicators among females only. Spearman correlation coefficients were also examined between exploratory latent variables of PA (described in table 4.4) and the various cardiometabolic indicators (table 4.5). The only statistically significant correlation between the principal component factors and the outcomes was between CRP and moderate lifestyle domestic activity among males. This negative correlation was of a weak magnitude but was of a greater strength than those from the individual measures of similar activities alone.

Independent associations between PA, SED, and android BF%

Standard scores of the objective measures and total activity scores from self-reported measures for both PA and SED were entered into multivariate linear regression models to determine their independent association with android BF%. Results are presented in table 4.6. Mean daily step count from the New Lifestyles 1000 accelerometer and the total activity score from the Godin Leisure Time Exercise Questionnaire were the PA measures independently associated with android BF%, suggesting that the relationship may be related more to dose of activity than intensity among this study population (model $R^2 = 0.35$). The association was strongest with the objective measure of steps, with a one standard deviation increase in steps associated with two-times as strong of a decline in BF% than with a similar increase in Godin total activity, though both are modest changes in %BF. No interaction was seen by gender with either measure. No independent predictors were seen for SED.

Relationships between PA and SED measures and HOMA, CRP, and PDAY

Tables 4.7 and 4.8 present gender-adjusted prevalence odds ratios for having a cardiometabolic measure above the 85th percentile across quartiles of each total PA/SED measure. Significant associations were seen for Godin total activity, with those in the highest, compared to the lowest, quartile of self-reported activity having a 50% lower odds of being at high risk for an elevated HOMA level. Trends across quartiles of steps with HOMA and television viewing with CRP approached statistical significance. A 50% reduction in odds of an elevated HOMA score was observed across the extreme categories of steps. A greater than 90% increased odds of a high risk CRP was seen among those subjects with the greatest television viewing time. Multiple measure logistic regression models provided no significant multi-measure models, however Godin total activity was identified as an independent predictor for elevated HOMA. Adjustment for android BF% attenuated the associations slightly. Tests of interaction between gender and Godin total activity were non-significant (likelihood ratio $p = 0.75$).

Included in the appendix (Appendices 4 - 9), similar analyses as above were also performed with the self-reported component measures of PA, stratified by gender. Models varied substantially by gender and outcome. Of note, a significant association was observed across tertiles of Godin moderate intensity activity and HOMA, with those in the highest third having a 62% lower odds of an elevated HOMA score among females. Among the male subjects, Godin vigorous activity appeared to have a protective effect on the prevalence of a high risk HOMA (82% decrease in risk among highest group compared to lowest). We also observed a reduction in the prevalence of a high CRP level for males with the most IPAQ domestic activity, of about 70%. The best multiple measure models among females retained Godin moderate and IPAQ vigorous activity for HOMA, Godin and IPAQ moderate, and IPAQ domestic activities for CRP, and IPAQ vigorous activity for PDAY. Less independent associations were seen among the best multiple measure models among male subjects. Godin vigorous and IPAQ work activities were retained as significant independent predictors of HOMA, while IPAQ domestic activity was the only retained predictor of CRP. No independent predictors of risk of an elevated PDAY were retained for males. Following the adjustment of the final multiple measure models for android BF%, only slight attenuations were observed in the coefficients in most cases.

Also presented in appendices 10 - 12 are the unadjusted and adjusted prevalence odds ratios for the self-reported SED measures and each of the cardiometabolic outcomes, again stratified by gender. A trend of positive association (or suggestion of association) was observed across groups of females with the greatest reported television viewing time for both an increased odds of a high risk HOMA and CRP level, compared to those in the lowest group. Television viewing time was retained as a significant independent predictor of HOMA and CRP for females only, following adjustment for self-reported sitting time. Self-reported IPAQ sitting time was independently associated with risk of a higher PDAY risk score in male subjects.

Latent variables of PA and SED and their predictive ability

In order to compare the predictive ability of latent variables of PA versus the individual field measures of increased cardiometabolic risk, ROC areas computed from logistic regression models were compared using a chi-square test (table 4.7). A model including the total PA score was compared against each of the objective measures and summary self-report measures. All ROC areas were of a very weak magnitude and those from latent variables were not of a greater predictive ability than the field measures. Principal component factor loadings are included in appendices 13 – 14.

Interaction effects between PA/SED and android BF%

Likelihood ratio tests were used to examine any interaction effects present between differing levels of PA, SED, and the indicators of cardiometabolic health. Similar tests were also performed to determine if DXA-measured body composition modified the effect of PA or SED on HOMA, CRP, or PDAY. Because no multiple measure models were retained from earlier analyses, interaction effects were examined among individual measures of activity. No significant interaction effects were seen. The interaction term coefficients were non-significant and the log likelihoods did not statistically differ between nested models.

4.4 Discussion

In this cross-sectional descriptive study of 402 college freshmen, we examined the associations between PA, SED, and indicators of cardiometabolic risk. Prior research suggests that subjective estimates of PA and SED are inferior to objective measures at predicting cardiometabolic health outcomes [32]. For example, Celis-Morales et al. compared the relationships between accelerometer and IPAQ-derived PA and SED with various cardiometabolic risk factors. They observed that only some of the associations between PA, SED, and risk factors that were seen with an accelerometer could be recognized with IPAQ measures [21].

Such a trend was not uniformly observed among the accelerometer and the self-report measures of PA and SED in this study. All correlation coefficients, across genders and outcomes, were of a weak magnitude, but were generally stronger among female participants. The patterns of associations differed by gender, as has been observed in prior studies. The Childhood Determinants of Adult Health study reported significant associations between HOMA and IPAQ total activity and several IPAQ component measures among males, and significant associations between HOMA and television watching and pedometer steps per day among females [22]. Likewise, we observed that steps were more strongly related to the outcomes in females than males but we did not observe the greater associations with IPAQ measures among males. The objectively-measured steps were the most consistently associated measure with the cardiometabolic outcomes among females, but these associations were not of a greater magnitude than those seen with self-reported measures. No discernible patterns were observed among males. The PDAY risk score was not associated with any of the measures among either gender while android BF% among females was most consistently associated with the PA measures used in this study. The self-reported measures of SED were not significantly associated with the outcome measures, except for television viewing with CRP and android BF% among females. A prior study observed stronger relationships between SED and risk factors than with moderate-vigorous PA and risk factors among a sample of 317 adults [21]. The study noted regression coefficients for HOMA that were >50% lower for the IPAQ-reported SED compared to the accelerometer-derived SED. Although no objective measure specific to SED was available in this study for the entire sample, no such associations were seen in this study.

Previous studies have indicated that different relationships between PA and SED with health outcomes may be revealed through different measurement approaches [21].

The current study aimed to determine associations between a variety of measures of PA and SED and an increased risk of having an elevated level of a cardiometabolic health indicator. Identifying these relationships helps to inform practice of the best type of measurement tool for use among college students when the goal is to identify those at an increased risk for cardiometabolic-related health problems. It was hypothesized that each of the field measures of PA and SED would be associated with at least one of the cardiometabolic health indicators. In general, this hypothesis was not supported by the main analyses. The IPAQ total activity score, IPAQ sitting time, and television viewing time were not independently associated with any of the outcomes. In sub-analyses, however, when the self-reported component scores and the SED measures were analyzed stratified by gender, television viewing and select indices of the IPAQ and Godin instruments were associated with at least one outcome measure among either gender.

Latent variables of PA were created to summarize the different PA measures into one index score. The ability of these latent variables to better predict the prevalence of risk of each cardiometabolic health indicator than each of their component measures was assessed with a comparison of ROC area between models. There were no statistically significant differences seen between latent variables and each of the summary field measures of PA across HOMA, CRP, or PDAY. Additionally, all models were of a poor predictive ability. These findings indicate that combining the information gathered from multiple measures of PA to predict those at an elevated risk may not be more beneficial than the use of a single well-chosen measure. Several studies have successfully combined multiple measurement techniques in order to more fully describe subject PA profiles [33, 34]; however the use of latent variables for this purpose is a novel aspect of the current study. Despite the lack of improved predictive ability and the difficulty in interpreting latent variables, the combination of the multiple measurement approaches in this study did serve to more completely describe the PA of college students in a qualitative sense. No significant latent variables could be created for SED. Of note, an orthogonal rotation was used in these analyses which may be a limitation of the study, due to the correlations that are present between our various measures.

Existing research suggests that the negative health implications associated with excessive SED is independent of PA participation [35], however this is not a universal finding [36].   To investigate the effects of PA on the relationships between SED and cardiometabolic risk (and vice versa), interaction effects between these two behaviors were examined. No statistically significant interaction effects were seen, which did not support our hypothesis. Accelerometer steps were used as the interaction variable of PA as it was shown in earlier work to be strongly associated with a criterion measure of PA [37]. IPAQ self-reported sitting time was used for SED. Though the IPAQ sitting time estimates have been shown to be substantially underreported in comparison to a criterion measure, many subjects unexpectedly reported no to very little television viewing time, suggesting that the IPAQ sitting time measure was the best available measure of SED in the current study. However, as this measure was not associated with any of the study outcomes, the lack of interaction effect may be a result of the inaccuracies in the SED measures.

The current study also sought to determine if the relationships between PA/SED and cardiometabolic health indicators varied based on DXA-measured body composition. It was hypothesized that associations between measures of PA/SED and cardiometabolic health indicators would be stronger among those with higher body fat percentages in comparison to those with lower levels. No interaction effects were seen, however, in models with individual measures of PA/SED and the cardiometabolic outcomes. Prior research reports that physical inactivity is correlated with some cardiometabolic risk indicators, such as CRP, independent of obesity [38] and that fatness and fitness (associated with PA and SED) are separate entities [13]. The evidence is mixed, however, as LeCheminant et al. reported that the relationships between PA and CRP levels in middle-age women are largely a function of differences in BF% [39]. Generally these studies view body composition as a confounding factor, however, and not as a potential effect modifier. The use of BMI or waist circumference to indicate body composition, instead of the gold-standard measure from a DXA scan, has been most common.

Although the present study helps to describe the relations between different measures of PA and SED and their respective associations with indicators of cardiometabolic risk, the study is not without substantial limitations. The cross sectional nature of the study precludes any causal relationships from being determined. Additionally, no true objective measure of SED was available in the entire sample, which may have increased the sensitivity of the SED measures. The use of a triaxial accelerometer, such as an Actigraph, in place of the piezoelectric pedometer-style device used in this study may have provided a more accurate quantification of PA in addition to a routinely used indicator of SED. Due to the lower than expected levels of television viewing reported, a question addressing all seated screen time activities instead of only those watched on a television may have been more appropriate to the study population.

Finally, while approximately 10% of the freshmen class participated in this study, low variability was observed among the levels of HOMA, CRP, and PDAY. The generally good health seen in this study required the use of a percentile threshold to indicate an elevated risk, a threshold that could be below clinical significance and thus limit the ability to detect any true associations between PA, SED, and risk. Future work should attempt to include a greater number of students who may have clinically significant elevations in these indicators. One possible strategy could be to target students who have been identified previously by a university-affiliated health center as having clinically meaningful elevations in risk factors.

In conclusion, the current study examined associations between commonly used measures of PA and SED with indicators of cardiometabolic health among college freshmen. This appears to be one of the first studies to examine the use of latent variables as summary measures of PA and SED in comparison to their individual measures. This is important to investigate because a large burden is associated with the use of multiple measures, both on the subjects and the research project, so their use must be justified. The relatively limited number of significant and independent associations between the measures and outcomes suggest several possible conclusions: 1) relationships are not present among this population group, 2) several of the measures may not be appropriate for use among college students, 3) college students are not able to accurately self-report their activity behaviors and that the objective tool used may not capture all of their PA, or 4) HOMA, CRP, and PDAY are not sensitive indicators of cardiometabolic risk among this demographic. The latent variables used in this study did not perform better than the individual field measures. Differences among measures and outcomes suggest that both PA and SED are complex behaviors and that their universal effect on cardiometabolic health may not be best approached with a single tool across all population groups.

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Table 4.1 Participant demographics by gender

Characteristic		**Females** (n = 276)		**Males** (n = 126)		p-value
		Mean ± SD/%	Median (25th, 75th)	Mean ± SD/%	Median (25th, 75th)	
Age (years)		18.3 ± 0.5	18 (18, 19)	18.4 ± 0.5	18 (18, 19)	0.50
Ethnicity	White	65.2%	--	69.8%	--	0.56
	Black	12.0%	--	8.7%	--	--
	Asian	14.5%	--	15.9%	--	--
	Hispanic	5.4%	--	4.8%	--	--
	Other	2.9%	--	0.8%	--	--
Height (cm)		164.3 ± 6.3	164.4 (160.2, 168.8)	177.3 ± 6.6	177.5 (173.2, 181.6)	<0.01
Weight (kg)		62.3 ± 10.5	60.8 (55.1, 67.8)	73.4 ± 12.5	71.5 (65.8, 79.4)	<0.01
BMI (kg/m^2)		23.0 ± 3.6	22.4 (20.6, 24.6)	23.3 ± 3.4	23.2 (21.3, 24.8)	0.51
Total adiposity (%)		33.3 ± 5.8	32.8 (29.3, 36.9)	19.7 ± 5.9	19.3 (15.3, 21.6)	<0.01
Android adiposity (%)		35.7 ± 10.4	35.0 (27.9, 42.3)	20.7 ± 10.3	18.9 (13.1, 24.8)	<0.01
Total cholesterol (mg/dL)		165.0 ± 30.4	160.5 (146.0, 181.8)	148.7 ± 28.0	149 (132, 163)	<0.01
HDL cholesterol (mg/dL)		60.4 ± 14.2	59.0 (50.0, 69.8)	49.6 ± 11.5	49 (43, 57)	<0.01
LDL cholesterol (mg/dL)		87.9 ± 26.6	85.0 (71.3, 100.8)	83.3 ± 25.5	81.0 (70.0, 97.3)	0.09
Triglycerides (mg/dL)		83.6 ± 36.6	75 (58, 101)	79.1 ± 35.3	73.0 (54.3, 91.3)	0.22
Glucose (mg/dL)		84.6 ± 6.4	84 (81, 88)	87.3 ± 6.3	87.0 (83.4, 90.3)	<0.01
Insulin (IU/mL)		3.4 ± 3.8	2 (1, 5)	2.5 ± 3.1	1 (1, 3)	<0.01
HOMA		0.7 ± 0.9	0.4 (0.2, 1.0)	0.5 ± 0.7	0.2 (0.2, 0.6)	0.29
C-reactive protein (mg/dL)		1.7 ± 3.2	0.6 (0.2, 1.6)	1.4 ± 2.6	0.4 (0.1, 1)	0.03
Systolic blood pressure		111.8 ± 10.8	112.5 (104.0, 119.0)	122.3 ± 11.0	121.5 (114.8, 129.3)	<0.01
Diastolic blood pressure		69.2 ± 8.9	69.0 (63.0, 75.5)	70.0 ± 8.5	70.5 (63.5, 76.5)	0.37
Heart rate (bpm)		73.6 ± 11.5	73.5 (65.0, 80.5)	71.0 ± 15.2	70.5 (59.5, 79.5)	0.02
Current smokers		5.4%	--	11.1%	--	0.04
PDAY risk score		-0.8 ± 1.8	-1 (-2, -1)	0.8 ± 2.1	0 (0, 1)	<0.01

All blood measures fasting; Heart rate and blood pressure measures obtained in seated, resting state; Smoking status self-reported

Table 4.2 Physical activity and sedentary behavior characteristics by gender

Characteristic	**Females** (n = 276) Mean ± SD/%	**Females** (n = 276) Median (25th, 75th)	**Males** (n = 126) Mean ± SD/%	**Males** (n = 126) Median (25th, 75th)	p-value[a]
Physical Activity					
New Lifestyles 1000					
Steps/d	10978 ± 3428	10544 (8635, 12548)	11537 ± 2926	11248 (9579, 13248)	0.05
Activity time (hr/d)	51.2 ± 21.9	48.1 (35.6, 63.4)	46.9 ± 18.9	45.5 (32.7, 58.7)	0.06
Godin Leisure Time					
Total activity	52.1 ± 31.2	49 (31, 70)	60.2 ± 37.2	55 (38, 78)	0.03
Mild activity	13.6 ± 13.7	15 (3, 21)	13.9 ± 14.8	12 (3, 21)	0.79
Moderate activity	15.5 ± 13.5	15 (5, 25)	16.3 ± 17.9	15 (5, 25)	0.97
Vigorous activity	23.1 ± 18.2	18 (9, 36)	30.7 ± 18.4	27 (18, 45)	<0.01
IPAQ (MET-min/week)					
Total activity	4694 ± 4019	3777 (1826, 6418)	5815 ± 5761	4627 (2676, 7373)	0.02
Walking activity	2294.5 ± 2239.9	1485.0 (783.8, 2986.5)	2190.7 ± 2378.3	1510 (924, 2772)	0.99
Moderate activity	1302.1 ± 2186.6	540 (120, 1718)	1761.3 ± 2954.9	787.5 (240.0, 2232.5)	0.03
Vigorous activity	1517.4± 2022.7	960 (0, 1920)	2237.1 ± 2980.8	1440 (330, 2880)	<0.01
Work activity	712.4 ± 2028.9	0 (0, 0)	824.9 ± 2707.0	0 (0, 0)	0.56
Travel activity	1807.5± 1786.5	1188 (693, 2376)	1730.9 ± 2045.2	1386 (693, 2079)	0.99
Domestic activity	659.6 ± 1321.8	180 (0, 664)	808.8 ± 1323.7	180 (0, 1200)	0.94
Recreation activity	1962.0 ± 2361.8	1254 (438, 2760)	2856.6 ± 3703.6	1920 (596, 4056)	<0.01
Sedentary Behavior					
TV viewing time (hr/d)	0.9 ± 1.3	1 (0, 1)	1.2 ± 1.6	1 (0, 2)	0.16
IPAQ (hr/d)					
Total sitting, weighted avg	5.7 ± 2.6	5.3 (3.9, 7.0)	5.7 ± 3.0	5.0 (3.7, 7.3)	0.48

[a]Wilcoxon rank-sum tests

Note: IPAQ total activity includes sum of intensity and/or domain-specific estimates; Godin is unitless measure

Table 4.3 Spearman correlations between cardiometabolic health indicators and measures of physical activity and sedentary behavior by gender

	Females				Males			
	HOMA	CRP	PDAY	Android BF%	HOMA	CRP	PDAY	Android BF%
Physical Activity								
NL-1000 steps/d	-0.12*	-0.16*	-0.09	-0.16**	-0.03	0.04	-0.08	-0.19*
NL-1000 activity minutes/d	-0.09	-0.19*	-0.10	-0.18**	0.04	-0.003	0.05	-0.15
Godin total activity	-0.08	-0.08	-0.09	-0.20**	-0.16	-0.10	-0.07	-0.07
Godin light activity	-0.09	-0.03	-0.02	-0.09	-0.21*	-0.08	0.09	0.03
Godin moderate activity	-0.07	-0.05	-0.004	-0.12	-0.01	-0.09	-0.03	-0.05
Godin vigorous activity	-0.03	-0.08	-0.07	-0.15*	-0.05	-0.09	-0.15	-0.11
IPAQ total met-min/wk	-0.07	0.06	-0.02	-0.15*	-0.15	-0.07	-0.13	-0.08
IPAQ walk total	-0.001	0.03	0.04	-0.07	-0.02	-0.16	0.01	0.05
IPAQ moderate activity	-0.03	0.14*	0.02	-0.09	-0.07	-0.03	-0.13	-0.11
IPAQ vigorous activity	-0.15*	-0.04	-0.09	-0.21**	-0.16	-0.05	-0.12	-0.10
IPAQ recreation activity	-0.17*	-0.03	-0.05	-0.17**	-0.23*	-0.07	-0.14	-0.13
IPAQ domestic activity	-0.05	0.10	0.08	-0.14*	-0.08	-0.12	-0.09	-0.11
IPAQ travel activity	0.03	0.02	0.004	-0.11	-0.01	-0.17	-0.04	0.000
IPAQ work activity	0.01	0.06	0.05	0.08	0.05	0.03	-0.05	0.001
Sedentary Behavior								
IPAQ sit time (hr/d)	0.03	-0.02	0.07	0.02	0.002	-0.01	0.07	0.04
TV viewing time (hr/d)	0.09	0.24**	0.07	0.16*	-0.01	0.01	0.08	0.12

*Significant correlation at $p < 0.05$; ** Significant correlation at $p < 0.01$

NL= New Lifestyles accelerometer; IPAQ = International Physical Activity Questionnaire; TV = television; HOMA = homeostasis model assessment; CRP = high-sensitivity C-reactive protein; PDAY = Pathobiological Determinants of Atherosclerosis in Youth risk score; BF% = body fat percentage

Table 4.4 Details of principal component factors for physical activity by gender

	Variance Explained	Mean ± SD
Physical Activity- Females		
Light to moderate lifestyle activity	39%	
Recreational and vigorous activity	18%	
Mild to moderate exercise activity	10%	
Objectively measured activity	9%	
Total summary PA latent variable		0 ± 0.45
Physical Activity- Males		
Recreational and vigorous activity	32%	
Work and travel activity	16%	
Mild to moderate exercise activity	14%	
Moderate lifestyle domestic activity	11%	
Objectively measured activity	7%	
Total summary PA latent variable		0 ± 0.41

Retained factors from normalized physical activity measures, with Eigenvalue > 1.0. Mean score computed by summing individual principal component scores, each weighted for its relative contribution in the explained variance

Table 4.5 Spearman correlations between cardiometabolic health indicators and latent summary variables of physical activity by gender

	HOMA	CRP	PDAY
Physical Activity- Females			
Light to moderate lifestyle activity	-0.06	-0.01	0.04
Recreational and vigorous activity	-0.10	0.07	0.03
Mild to moderate exercise activity	-0.10	-0.09	-0.05
Objectively measured activity	-0.11	-0.12	0.03
Total summary PA latent variable	-0.11	-0.002	-0.01
Physical Activity- Males			
Recreational and vigorous activity	-0.10	0.03	-0.15
Work and travel activity	0.07	0.01	0.15
Mild to moderate exercise activity	0.02	-0.09	0.04
Moderate lifestyle domestic activity	-0.09	-0.24*	-0.11
Objectively measured activity	0.003	-0.02	-0.05
Total summary PA latent variable	-0.05	-0.07	-0.09

* Signficant at $p < 0.05$

HOMA = homeostasis model assessment; CRP = high-senstivity C-reactive protein; PDAY = Pathobiological Determinants of Atherosclerosis in Youth risk score

Table 4.6 Predictors of android body fat from summary measures of activity

	Measures of Physical Activity	
Measure[a]	β	*p*
NL-1000 mean steps/d[b]	-1.85	<0.01
Godin total activity[c]	-0.89	0.09
Model R^2	0.35	<0.001
	Measures of Sedentary Behavior	
Measure[a]	β	*p*
	None retained	

NL = New Lifestyles

Multivariate linear regression model with forward stepwise selection; Alpha set at 0.10

[a]All measures are standard scores

All models adjusted for gender, interaction terms (p = 0.74[b] , p = 0.98[c])

Table 4.7 Associations between cardiometabolic risk and measures of physical activity

		HOMA ≥ 85th percentile			CRP ≥ 85th percentile			PDAY ≥ 85th percentile		
			Gender-adjusted model			Gender-adjusted model			Gender-adjusted model	
Categorical Measure		%	POR	95% CI	%	POR	95% CI	%	POR	95% CI
NL-1000 steps	Q1	16.0	1.00	Referent	20.0	1.00	Referent	14.0	1.00	Referent
	Q2	19.8	1.29	0.62, 2.67	11.9	0.53	0.24, 1.15	12.9	0.90	0.40, 2.03
	Q3	16.8	1.05	0.50, 2.24	15.8	0.73	0.35, 1.51	16.8	1.23	0.57, 2.66
	Q4	8.0	0.45	0.18, 1.12	15.0	0.68	0.32, 1.42	16.0	1.15	0.53, 2.53
	p trend		0.09			0.50			0.53	
NL-1000 activity minutes	Q1	16.5	1.00	Referent	23.3	1.00	Referent	17.5	1.00	Referent
	Q2	17.2	1.05	0.50, 2.19	13.1	0.50	0.24, 1.05	7.1	0.36	0.14, 0.91
	Q3	17.0	1.04	0.50, 2.16	13.0	0.49	0.24, 1.03	17.0	0.97	0.47, 2.01
	Q4	10.0	0.56	0.24, 1.29	13.0	0.50	0.24, 1.05	18.0	1.05	0.51, 2.17
	p trend		0.22			0.05			0.49	
IPAQ total activity	Q1	21.0	1.00	Referent	16.0	1.00	Referent	16.0	1.00	Referent
	Q2	11.9	0.50	0.23, 1.09	13.9	0.82	0.38, 1.80	15.8	0.97	0.45, 2.10
	Q3	10.0	0.41	0.18, 0.94	16.0	0.97	0.45, 2.07	16.0	0.98	0.45, 2.10
	Q4	18.0	0.82	0.40, 1.66	17.0	1.04	0.49, 2.21	12.0	0.70	0.31, 1.58
	p trend		0.50			0.75			0.46	
Godin total activity	Q1	24.7	1.00	Referent	17.5	1.00	Referent	17.5	1.00	Referent
	Q2	12.2	0.42	0.20, 0.91	15.3	0.84	0.39, 1.80	15.3	0.84	0.39, 1.81
	Q3	10.1	0.34	0.15, 0.76	15.2	0.83	0.39, 1.78	14.1	0.77	0.36, 1.67
	Q4	13.5	0.47	0.22, 1.00	12.5	0.66	0.29, 1.47	12.5	0.66	0.30, 1.48
	p trend		0.03			0.35			0.32	

HOMA = homeostasis model assessment; CRP = C-reactive protein; PDAY = Pathobiological Determinants of Atherosclerosis in Youth; POR = prevalence odds ratio; CI = confidence interval; NL = New Lifestyles; IPAQ = International Physical Activity Questionnaire

Table 4.8 Associations between cardiometabolic risk and measures of sedentary behavior

Categorical Measure		HOMA ≥ 85th percentile %	HOMA Gender-adjusted model POR	HOMA Gender-adjusted model 95% CI	CRP ≥ 85th percentile %	CRP Gender-adjusted model POR	CRP Gender-adjusted model 95% CI	PDAY ≥ 85th percentile %	PDAY Gender-adjusted model POR	PDAY Gender-adjusted model 95% CI
IPAQ sitting	Q1	12.1	1.00	Referent	14.1	1.00	Referent	11.1	1.00	Referent
	Q2	16.5	1.43	0.65, 3.18	14.6	1.04	0.47, 2.29	22.3	2.30	1.06, 5.03
	Q3	13.8	1.16	0.49, 2.74	16.1	1.19	0.53, 2.67	10.3	0.93	0.37, 2.37
	Q4	16.5	1.43	0.64, 3.21	18.6	1.39	0.65, 2.97	14.4	1.35	0.58, 3.14
	p trend		0.51			0.37			0.91	
Television viewing	Q1	13.2	1.00	Referent	12.1	1.00	Referent	14.9	1.00	Referent
	Q2	16.5	1.30	0.67, 2.51	16.5	1.43	0.73, 2.80	13.0	0.85	0.43, 1.68
	Q3	20.7	1.71	0.79, 3.71	20.7	1.89	0.86, 4.13	19.0	1.32	0.61, 2.88
	Q4	14.3	1.10	0.41, 2.89	21.4	1.94	0.81, 4.63	14.3	0.93	0.36, 2.44
	p trend		0.41			0.05			0.80	

HOMA = homeostasis model assessment; CRP = C-reactive protein; PDAY = Pathobiological Determinants of Atherosclerosis among Youth; POR = prevalence odds ratio; CI = confidence interval; IPAQ = International Physical Activity Questionnaire

Table 4.9 Comparison of predictive ability of latent variables versus field measures of cardiometabolic risk by gender

	HOMA ≥ 85th percentile		CRP ≥ 85th percentile		PDAY ≥ 85th percentile	
Variable	ROC area	p value[a]	ROC area	p value[a]	ROC area	p value[a]
<u>Physical Activity- Females</u>						
Field Measures						
NL-1000 steps	0.61		0.56		0.53	
NL-1000 activity minutes	0.60		0.60		0.52	
IPAQ total activity	0.57		0.53		0.51	
Godin total activity	0.59		0.52		0.54	
Latent Variable						
Total physical activity	0.59	0.73	0.50	0.52	0.50	0.82
<u>Physical Activity- Males</u>						
Field Measures						
NL-1000 steps	0.50		0.51		0.56	
NL-1000 activity minutes	0.57		0.50		0.51	
IPAQ total activity	0.53		0.58		0.54	
Godin total activity	0.57		0.60		0.57	
Latent Variable						
Total physical activity	0.54	0.35	0.56	0.13	0.57	0.61

HOMA = homeostasis model assessment; CRP = high-sensitivity C-reactive protein; PDAY = Pathobiological Determinants of Atherosclerosis in Youth; ROC = receiver operator characteristic; NL = New Lifestyles; IPAQ = International Physical Activity Questionnaire

[a]Chi square p values comparing ROC area between all measures

CHAPTER 5

SUMMARY AND CONCLUSIONS

The findings of the current study add to the body of literature including the accuracy of measurement tools and their relations with health outcomes. The measurement of physical activity and sedentary behavior is becoming an increasingly common component of many research studies and interventions. Though great progress has occurred, measurement of these complex behaviors remains an evolving science. As such, the interrelationships between various measurement tools have yet to be fully described. It is well established that physical activity is associated with many health-related outcomes. Sedentary behavior is also quickly being recognized as an important modifiable behavior with health consequences. To fully describe the relations between these behaviors and health outcomes, it is crucial that the different facets of these behaviors are assessed accurately and that their potential associations with health are understood as completely as possible. The best measurement approach likely differs by the outcome(s) of interest and the population group, indicating that these associations should be studied in diverse settings and situations.

Technological advances have increased the accuracy of objective measurement tools and their feasibility of use. Important limitations of objective measures must be recognized, including their cost and inability to capture all types of activity or to provide information on the context of an activity. Subjective approaches remain commonly used, in part because they do not have these same limitations. Results from the current study highlight the importance of considering a measurement tool appropriate to one's aims, population group, and outcomes of interest, and may include a combination of both an objective and subjective measure.

The first portion of the current study used the activPAL as a criterion measure for both physical activity and sedentary behavior. Objective measures of physical activity were most closely related to the criterion measure, yet the subjective measures were able to reveal the domains and intensities of activity that are most common among college students, such as travel and leisure activities including walking and those of a vigorous intensity. This information would have remained elusive with an objective-only measurement approach. Future research among college students aiming to quantify total activity should be sure to select a measurement approach that would assess these specific activities, including walking around campus and structured vigorous exercise bouts. Additionally, the current study suggests that self-reported estimates of sitting time by college students should be utilized with caution, due to substantial underreporting. It is apparent from this study that television viewing time is not a good indicator of total screen time in this population. A questionnaire designed to assess all of the seated screen time activities in which college students participate would be ideal, and may include television, computer, tablet, and smart phone use. It must also be recognized that the criterion measure has its own set of limitations. The activPAL is unable to capture all forms of PA, including upper body movement and subjects did not wear the monitor during activities involving water. Also, the output from the activPAL that was used to quantify PA in this study closely aligned with the type of information provided by the New Lifestyles 1000 accelerometer. The use of a different criterion measure of PA, such as doubly labeled water to measure total energy expenditure, a combination heart rate monitor and accelerometer to better assess intensity of activity, or a global positioning satellite device to provide more information on the context of activity, would have supplied additional insight unique from the New Lifestyles monitor.

Following the investigation of relationships between subjective and objective measures with each other and with a criterion measure, the various measures were applied to determine their associations with health outcomes. The current study suggests that, among college students, few of the measures of physical activity and sedentary behavior are independently associated with indicators of cardiometabolic disease risk. Existing research suggests that objective measures of these behaviors are more strongly associated with risk than subjective measures; this finding was not fully supported by the present findings. In practice, the simple Godin Leisure Time Exercise Questionnaire performed better than the more comprehensive International Physical Activity Questionnaire at predicting an increased risk of having a high level of cardiometabolic disease indicators. Findings from the present study also suggest that gender differences may exist. Differences in total activity as well as type of activity have previously been reported between genders and this may have implications on the ideal measurement approach as well as associations with health. Future research should continue to examine the independent and joint associations of various commonly used PA and SED measurement tools with different health outcomes. Moreover, these associations should be examined among a more heterogeneous population group, while considering the behavioral and biological differences that exist between genders. The inclusion of a greater number of subjects with clinically significant levels of cardiometabolic disease risk factors would also be advantageous. The sample for the current study was largely of good health, as defined by the outcomes used for this project, which may have masked any findings that are apparent among a truly high-risk population. Among a sample with a greater proportion of subjects at high risk, independent associations between measures of PA and SED and the risk indicators may be more likely. The relatively homogenous population of our study also limits the generalizability of our findings.

A novel aspect of the current study was the creation of exploratory latent variables to summarize the activity information garnered from the multiple measurement tools. Although the complementary aspect of different measurement approaches are recognized, thus far relatively few studies have attempted to combine their information into a unified summary measure of the respective behavior. The current study found that the latent variables created in this project were not superior to the individual field measures in their associations with the activPAL criterion measure or in their ability to predict those at high risk for an elevated level of a cardiometabolic disease indicator. The idea of utilizing complementary measurement approaches has theoretical advantages yet these must be established before the practice becomes more commonplace; an increased burden is created with multiple tools. Future research should examine different approaches to combining the information from multiple tools into a meaningful variable. The measures used in the current study primarily estimated total activity and moderate to vigorous physical activity. Thus, the latent variables perhaps did not add enough additional and unique information to the individual measures to be advantageous. Utilizing other aspects of the different measures, such as estimates of the frequency of certain types of activities across a given time period, could potentially contribute more information to summary measures and most accurately present one's true activity level. For example, the combination of an objective measure and an activity diary could potentially provide information on the dose of activity, the types of activity performed, and if specific types of activities were dispersed throughout a week or concentrated on select days. Many questionnaires, including those used in the current study, inquire about the number of times per day or week a certain type of activity is performed. These details could possibly offer additional useful information that may be related to health outcomes, in addition to that appreciated by only examining total amounts of activity.

Results from this study are projected to inform optimal PA and SED measurement literature as well as future health-related behavior interventions among college students. Young adults enrolled in college are at an important transitory period in life. The origins of subclinical disease may have already established themselves and behaviors performed during this time period tend to persist later in life. Additionally, the transition from adolescence to adulthood is frequently accompanied by a decline in physical activity and by excessive sedentary behavior. Fortunately the college environment may offer an ideal setting for public health-focused efforts. Understanding the ideal methods to assess health behaviors and health risk in this population subgroup will lead to better informed interventions aimed at promoting healthy and preventative lifestyles.

APPENDICES

Appendix 1. Pathobiological Determinants of Atherosclerosis in Youth (PDAY) risk score

Risk Factor		PDAY Risk Score Point Value
Sex[a]		
	Male	0
	Female	-1
Age, y[a]		
	15 - 19	0
	20 - 24	5
	25 - 29	10
	30 - 34	15
Non-HDL cholesterol level, mg/dL[b]		
	<130	0
	130 - 159	2
	160 - 189	4
	190 - 219	6
	≥ 220	8
HDL cholesterol level, mg/dL[b]		
	< 40	1
	40 - 59	0
	≥ 60	-1
Hyperglycemia[b,c]		
	Normoglycemic	0
	Hyperglycemic	5
Hypertension[d]		
	Normotensive	0
	Hypertensive	4
Smoking[a]		
	Nonsmoker	0
	Smoker	1
Obesity		
	Male, BMI ≥ 30	6
	Male, BMI < 30	0
	Female	0

BMI = body mass index (weight in kilograms/height in meters squared); HDL =high-

[a]Self-reported; [b]Fasting measure; [c]Determined by glucose level, normal <126 mg/dL; [d]Normal systolic <130mmHg and diastolic <85mmHg

Appendix 2. Participant demographics for females comparing full dataset to that with missing values

Characteristic	**Females** (n = 276) Mean ± SD/%	**Females** (n = 298) Mean ± SD/%	p-value
Age (years)	18.3 ± 0.5	18.3 ± 0.5	1.00
Ethnicity	--		0.98†
White	65.2%	65.1%	
Black	12.0%	12.4%	
Asian	14.5%	13.4%	
Hispanic	5.4%	6.0%	
Other	2.9%	3.0%	
Height (cm)	164.3 ± 6.3	164.3 ± 6.3	1.00
Weight (kg)	62.3 ± 10.5	62.2 ± 10.4	0.91
BMI (kg/m^2)	23.0 ± 3.6	23.0 ± 3.5	1.00
Total adiposity (% fat)	33.3 ± 5.8	33.4 ± 5.8	0.84
Android adiposity (% fat)	35.7 ± 10.4	35.7 ± 10.4	1.00
Total cholesterol (mg/dL)	165.0 ± 30.4	164.9 ± 30.1	0.97
HDL cholesterol (mg/dL)	60.4 ± 14.2	60.5 ± 14.3	0.93
LDL cholesterol (mg/dL)	87.9 ± 26.6	87.6 ± 26.2	0.90
Triglycerides (mg/dL)	83.6 ± 36.6	83.8 ± 36.4	0.92
Glucose (mg/dL)	84.6 ± 6.4	84.7 ± 6.4	0.85
Insulin (IU/mL)	3.4 ± 3.8	3.4 ± 3.7	1.00
HOMA insulin resistance	0.7 ± 0.9	0.7 ± 0.9	1.00
hs C-reactive protein (mg/L)	1.7 ± 3.2	1.8 ± 3.6	0.73
Systolic blood pressure (mmHg)	111.8 ± 10.8	111.7 ± 10.8	0.91
Diastolic blood pressure (mmHg)	69.2 ± 8.9	69.1 ± 8.8	0.89
Heart rate (bpm)	73.6 ± 11.5	73.7 ± 11.6	0.92
Smokers	5.4%	5.7%	1.00†
PDAY risk score	-0.8 ± 1.8	-0.8 ± 1.7	1.00

All blood measures were performed fasting; Heart rate and blood pressure measures obtained in seated, resting state; Smoking status self-reported

†Chi-square test of homogenity

Appendix 3. Participant demographics for males comparing full dataset to that with missing values

Characteristic		**Males** (n = 126) Mean ± SD/%	**Males** (n = 134) Mean ± SD/%	p-value
Age (years)		18.4 ± 0.5	18.4 ± 0.5	1.00
Ethnicity		--		0.35†
	White	69.8%	67.9%	
	Black	8.7%	11.2%	
	Asian	15.9%	15.7%	
	Hispanic	4.8%	4.5%	
	Other	0.8%	0.8%	
Height (cm)		177.3 ± 6.6	177.3 ± 6.7	1.00
Weight (kg)		73.4 ± 12.5	73.4 ± 12.2	1.00
BMI (kg/m^2)		23.3 ± 3.4	23.2 ± 3.3	0.81
Total adiposity (% fat)		19.7 ± 5.9	19.5 ± 5.8	0.78
Android adiposity (% fat)		20.7 ± 10.3	20.5 ± 10.2	0.88
Total cholesterol (mg/dL)		148.7 ± 28.0	148.8 ± 27.4	0.98
HDL cholesterol (mg/dL)		49.6 ± 11.5	49.9 ± 11.8	0.84
LDL cholesterol (mg/dL)		83.3 ± 25.5	83.3 ± 24.8	1.00
Triglycerides (mg/dL)		79.1 ± 35.3	78.2 ± 34.7	0.84
Glucose (mg/dL)		87.3 ± 6.3	87.3 ± 6.4	1.00
Insulin (IU/mL)		2.5 ± 3.1	2.5 ± 3.1	1.00
HOMA insulin resistance		0.5 ± 0.7	0.5 ± 0.7	1.00
hs C-reactive protein (mg/L)		1.4 ± 2.6	1.4 ± 2.6	1.00
Systolic blood pressure (mmHg)		122.3 ± 11.0	122.6 ± 10.9	0.83
Diastolic blood pressure (mmHg)		70.0 ± 8.5	70.0 ± 8.4	1.00
Heart rate (bpm)		71.0 ± 15.2	71.3 ± 15.4	0.87
Smokers		11.1%	11.2%	1.00†
PDAY risk score		0.8 ± 2.1	0.7 ± 2.0	0.69

All blood measures were performed fasting; Heart rate and blood pressure measures obtained in seated, resting state; Smoking status self-reported

†Chi-square test of homogenity

Appendix 4. Associations between HOMA and measures of PA for females

Measure		%	Unadjusted		Best multiple measure model		Δ in model with android BF%	
			POR	95% CI	POR	95% CI	POR	95% CI
Godin mild	T1	17.7	1.00	Referent	Not retained		Not retained	
	T2	16.4	0.91	0.40, 2.10				
	T3	12.0	0.64	0.30, 1.39				
	p trend		0.26					
Godin moderate	T1	22.6	1.00	Referent	1.00	Referent	1.00	Referent
	T2	7.8	0.29	0.10, 0.81	0.29	0.11, 0.80	0.27	0.09, 0.78
	T3	10.0	0.38	0.16, 0.90	0.41	0.17, 0.99	0.46	0.18, 1.15
	p trend		<0.01					
Godin vigorous	T1	19.8	1.00	Referent	Not retained		Not retained	
	T2	10.6	0.48	0.21, 1.10				
	T3	16.3	0.79	0.35, 1.75				
	p trend		0.69					
IPAQ walk	T1	18.9	1.00	Referent	Not retained		Not retained	
	T2	13.5	0.67	0.30, 1.50				
	T3	12.8	0.63	0.27, 1.44				
	p trend		0.26					
IPAQ moderate	T1	19.1	1.00	Referent	Not retained		Not retained	
	T2	12.9	0.63	0.28, 1.41				
	T3	13.3	0.71	0.31, 1.59				
	p trend		0.37					
IPAQ vigorous	T1	22.6	1.00	Referent	1.00	Referent	1.00	Referent
	T2	9.8	0.37	0.16, 0.88	0.38	0.16, 0.89	0.61	0.24, 1.53
	T3	13.5	0.53	0.24, 1.17	0.60	0.26, 1.40	0.85	0.34, 2.10
	p trend		0.08					
IPAQ recreation	T1	21.3	1.00	Referent	Not retained		Not retained	
	T2	11.8	0.49	0.22, 1.12				
	T3	12.4	0.52	0.23, 1.18				
	p trend		0.09					
IPAQ domestic	T1	18.2	1.00	Referent	Not retained		Not retained	
	T2	12.2	0.63	0.27, 1.45				
	T3	15.9	0.85	0.39, 1.88				
	p trend		0.68					
IPAQ travel	T1	20.2	1.00	Referent	Not retained		Not retained	
	T2	14.2	0.65	0.31, 1.39				
	T3	10.7	0.47	0.19, 1.17				
	p trend		0.09					
IPAQ work	T1	15.4	1.00	Referent	Not retained		Not retained	
	T2	16.7	1.10	0.39, 3.08				
	T3	13.3	0.84	0.28, 2.58				
	p trend		0.84					

Appendix 5. Associations between HOMA and measures of PA for males

Measure		%	Unadjusted		Best multiple measure model		Δ in model with android BF%	
			POR	95% CI	POR	95% CI	POR	95% CI
Godin mild	T1	16.0	1.00	Referent	Not retained		Not retained	
	T2	16.7	1.05	0.31, 3.60				
	T3	13.6	0.83	0.26, 2.62				
	p trend		0.76					
Godin moderate	T1	13.8	1.00	Referent	Not retained		Not retained	
	T2	11.8	0.83	0.23, 3.03				
	T3	19.4	1.50	0.46, 4.84				
	p trend		0.55					
Godin vigorous	T1	24.2	1.00	Referent	1.00	Referent	1.00	Referent
	T2	15.1	0.56	0.18, 1.68	0.63	0.20, 1.96	0.72	0.21, 2.49
	T3	5.4	0.18	0.03, 0.98	0.17	0.03, 0.913	0.24	0.04, 1.35
	p trend		0.03					
IPAQ walk	T1	14.6	1.00	Referent	Not retained		Not retained	
	T2	16.3	1.13	0.34, 3.74				
	T3	15.0	1.03	0.30, 3.53				
	p trend		0.96					
IPAQ moderate	T1	14.6	1.00	Referent	Not retained		Not retained	
	T2	17.1	1.20	0.36, 3.97				
	T3	12.5	0.83	0.23, 3.01				
	p trend		0.79					
IPAQ vigorous	T1	16.3	1.00	Referent	Not retained		Not retained	
	T2	18.2	1.14	0.37, 3.51				
	T3	10.3	0.59	0.16, 2.22				
	p trend		0.46					
IPAQ recreation	T1	19.5	1.00	Referent	Not retained		Not retained	
	T2	18.6	0.94	0.32, 2.82				
	T3	7.3	0.33	0.08, 1.37				
	p trend		0.13					
IPAQ domestic	T1	17.0	1.00	Referent	Not retained		Not retained	
	T2	19.4	1.18	0.38, 3.64				
	T3	7.5	0.40	0.10, 1.64				
	p trend		0.23					
IPAQ travel	T1	14.6	1.00	Referent	Not retained		Not retained	
	T2	18.2	1.30	0.40, 4.15				
	T3	12.5	0.83	0.23, 3.01				
	p trend		0.79					
IPAQ work	T1	13.7	1.00	Referent	1.00	Referent	1.00	Referent
	T2	7.7	0.52	0.06, 4.40	0.59	0.07, 5.08	0.62	0.07, 5.83
	T3	36.4	3.60	0.90, 14.30	4.26	1.00, 18.13	3.20	0.60, 17.30
	p trend		0.13					

Appendix 6. Associations between CRP and measures of PA for females

Measure		%	Unadjusted		Best multiple measure model		Δ in model with android BF%	
			POR	95% CI	POR	95% CI	POR	95% CI
Godin mild	T1	18.8	1.00	Referent	Not retained		Not retained	
	T2	11.9	0.59	0.24, 1.45				
	T3	13.0	0.64	0.30, 1.39				
	p trend		0.25					
Godin moderate	T1	18.5	1.00	Referent	1.00	Referent	1.00	Referent
	T2	7.8	0.37	0.13, 1.04	0.31	0.11, 0.90	0.31	0.11, 0.91
	T3	13.8	0.70	0.32, 1.53	0.57	0.25, 1.30	0.61	0.62, 1.41
	p trend		0.26					
Godin vigorous	T1	12.8	1.00	Referent	Not retained		Not retained	
	T2	14.4	1.15	0.50, 2.66				
	T3	16.3	1.32	0.55, 3.16				
	p trend		0.53					
IPAQ walk	T1	13.3	1.00	Referent	Not retained		Not retained	
	T2	19.1	1.53	0.68, 3.45				
	T3	11.6	0.86	0.35, 2.10				
	p trend		0.76					
IPAQ moderate	T1	13.5	1.00	Referent	1.00	Referent	1.00	Referent
	T2	12.9	0.96	0.40, 2.25	1.43	0.55, 3.76	1.55	0.59, 4.08
	T3	20.2	1.63	0.72, 3.67	4.41	1.46, 13.34	4.48	1.46, 13.77
	p trend		0.23					
IPAQ vigorous	T1	16.1	1.00	Referent	Not retained		Not retained	
	T2	12.0	0.71	0.30, 1.64				
	T3	16.9	1.05	0.48, 2.31				
	p trend		0.90					
IPAQ recreation	T1	15.7	1.00	Referent	Not retained		Not retained	
	T2	11.8	0.72	0.31, 1.69				
	T3	16.9	1.09	0.49, 2.41				
	p trend		0.83					
IPAQ domestic	T1	20.5	1.00	Referent	1.00	Referent	1.00	Referent
	T2	12.2	0.54	0.24, 1.23	0.42	0.17, 1.04	0.45	0.18, 1.12
	T3	13.6	0.61	0.27, 1.37	0.29	0.10, 0.82	0.30	0.10, 0.88
	p trend		0.21					
IPAQ travel	T1	12.4	1.00	Referent	Not retained		Not retained	
	T2	18.9	1.65	0.74, 3.68				
	T3	12.0	0.97	0.38, 2.48				
	p trend		0.99					
IPAQ work	T1	15.9	1.00	Referent	Not retained		Not retained	
	T2	6.7	0.38	0.09, 1.68				
	T3	16.7	1.06	0.38, 2.97				
	p trend		0.71					

Appendix 7. Associations between CRP and measures of PA for males

Measure		%	Unadjusted		Best multiple measure model		Δ in model with android BF%	
			POR	95% CI	POR	95% CI	POR	95% CI
Godin mild	T1	18.0	1.00	Referent	Not retained		Not retained	
	T2	16.7	0.91	0.27, 3.05				
	T3	18.2	1.01	0.35, 2.92				
	p trend		0.99					
Godin moderate	T1	19.0	1.00	Referent	Not retained		Not retained	
	T2	14.7	0.27	0.23, 2.35				
	T3	16.1	0.11	0.26, 2.64				
	p trend		0.69					
Godin vigorous	T1	15.2	1.00	Referent	Not retained		Not retained	
	T2	22.6	1.64	0.51, 5.23				
	T3	8.1	0.49	0.11, 2.30				
	p trend		0.39					
IPAQ walk	T1	19.5	1.00	Referent	Not retained		Not retained	
	T2	23.3	1.25	0.44, 3.59				
	T3	10.0	0.46	0.12, 1.70				
	p trend		0.27					
IPAQ moderate	T1	22.0	1.00	Referent	Not retained		Not retained	
	T2	22.0	1.00	0.35, 2.86				
	T3	7.5	0.29	0.07, 1.20				
	p trend		0.09					
IPAQ vigorous	T1	20.9	1.00	Referent	Not retained		Not retained	
	T2	11.4	0.48	0.15, 1.61				
	T3	20.5	0.97	0.33, 2.86				
	p trend		0.93					
IPAQ recreation	T1	24.4	1.00	Referent	Not retained		Not retained	
	T2	11.6	0.41	0.12, 1.35				
	T3	17.1	0.64	0.21, 1.90				
	p trend		0.39					
IPAQ domestic	T1	27.7	1.00	Referent	1.00	Referent	1.00	Referent
	T2	11.1	0.33	0.09, 1.15	0.33	0.10, 1.11	0.32	0.09, 1.10
	T3	10.0	0.29	0.08, 1.02	0.29	0.09, 0.98	0.32	0.09, 1.08
	p trend		0.03					
IPAQ travel	T1	19.5	1.00	Referent	Not retained		Not retained	
	T2	18.2	0.92	0.31, 2.74				
	T3	15.0	0.73	0.23, 2.35				
	p trend		0.60					
IPAQ work	T1	16.7	1.00	Referent	Not retained		Not retained	
	T2	15.4	0.91	0.18, 4.51				
	T3	27.3	1.88	0.45, 7.89				
	p trend		0.47					

Appendix 8. Associations between PDAY risk score and measures of PA for females

			Unadjusted		Best multiple measure model	
Measure		%	POR	95% CI	POR	95% CI
Godin mild	T1	19.8	1.00	Referent	Not retained	
	T2	10.4	0.47	0.18, 1.21		
	T3	13.0	0.60	0.28, 1.29		
	p trend		0.18			
Godin moderate	T1	14.5	1.00	Referent	Not retained	
	T2	9.4	0.61	0.23, 1.63		
	T3	18.8	1.36	0.64, 2.89		
	p trend		0.49			
Godin vigorous	T1	14.0	1.00	Referent	Not retained	
	T2	14.4	1.04	0.46, 2.36		
	T3	15.0	1.09	0.46, 2.60		
	p trend		0.85			
IPAQ walk	T1	12.2	1.00	Referent	Not retained	
	T2	14.6	1.23	0.52, 2.92		
	T3	16.3	1.40	0.59, 3.29		
	p trend		0.44			
IPAQ moderate	T1	13.5	1.00	Referent	Not retained	
	T2	15.1	1.14	0.49, 2.62		
	T3	14.3	1.07	0.45, 2.54		
	p trend		0.88			
IPAQ vigorous	T1	19.4	1.00	Referent	1.00	Referent
	T2	9.8	0.45	0.19, 1.08	0.45	0.19, 1.07
	T3	14.6	0.71	0.33, 1.56	0.71	0.33, 1.56
	p trend		0.35			
IPAQ recreation	T1	18.0	1.00	Referent	Not retained	
	T2	12.9	0.68	0.30, 1.53		
	T3	13.5	0.71	0.31, 1.61		
	p trend		0.40			
IPAQ domestic	T1	11.4	1.00	Referent	Not retained	
	T2	14.4	1.32	0.54, 3.19		
	T3	17.0	1.60	0.67, 3.81		
	p trend		0.28			
IPAQ travel	T1	11.2	1.00	Referent	Not retained	
	T2	18.9	1.84	0.81, 4.19		
	T3	12.0	1.10	0.41, 2.82		
	p trend		0.82			
IPAQ work	T1	13.1	1.00	Referent	Not retained	
	T2	20.0	1.66	0.62, 4.44		
	T3	16.7	1.33	0.47, 3.77		
	p trend		0.41			

Appendix 9. Associations between PDAY risk score and measures of PA for males

Measure		%	Unadjusted POR	Unadjusted 95% CI	Best multiple measure model POR	Best multiple measure model 95% CI
Godin mild	T1	14.0	1.00	Referent	Not retained	
	T2	23.3	1.87	0.57, 6.07		
	T3	13.6	0.97	0.30, 3.16		
	p trend		0.99			
Godin moderate	T1	17.2	1.00	Referent	Not retained	
	T2	11.8	0.64	0.18, 2.24		
	T3	16.1	0.92	0.28, 3.01		
	p trend		0.80			
Godin vigorous	T1	24.2	1.00	Referent	Not retained	
	T2	15.1	0.56	0.18, 1.68		
	T3	8.1	0.28	0.06, 1.20		
	p trend		0.06			
IPAQ walk	T1	17.1	1.00	Referent	Not retained	
	T2	14.0	0.79	0.24, 2.60		
	T3	17.5	1.03	0.32, 3.28		
	p trend		0.96			
IPAQ moderate	T1	19.5	1.00	Referent	Not retained	
	T2	19.5	1.00	0.33, 3.00		
	T3	10.0	0.46	0.12, 1.70		
	p trend		0.25			
IPAQ vigorous	T1	16.3	1.00	Referent	Not retained	
	T2	25.0	1.71	0.59, 5.00		
	T3	5.1	0.28	0.05, 1.48		
	p trend		0.19			
IPAQ recreation	T1	17.1	1.00	Referent	Not retained	
	T2	25.6	1.67	0.57, 4.90		
	T3	4.9	0.25	0.05, 1.34		
	p trend		0.13			
IPAQ domestic	T1	17.0	1.00	Referent	Not retained	
	T2	25.0	1.63	0.55, 4.80		
	T3	10.0	0.40	0.10, 1.64		
	p trend		0.26			
IPAQ travel	T1	14.6	1.00	Referent	Not retained	
	T2	15.9	1.10	0.34, 3.63		
	T3	17.5	1.24	0.37, 4.10		
	p trend		0.73			
IPAQ work	T1	14.7	1.00	Referent	Not retained	
	T2	15.4	1.05	0.21, 5.28		
	T3	27.3	2.18	0.51, 9.27		
	p trend		0.33			

Appendix 10. Associations between homeostasis model assessment and measures of sedentary behavior by gender

		Females					Males				
			Unadjusted		Adjusted[a]			Unadjusted		Adjusted[a]	
Measure		%	POR	95% CI	POR	95% CI	%	POR	95% CI	POR	95% CI
Television viewing	T1	12.9	1.00	Referent	1.00	Referent	14.0	1.00	Referent	Not retained	
	T2	12.8	0.99	0.42, 2.32	1.27	0.53, 3.05	24.3	1.97	0.65, 6.01		
	T3	23.4	2.07	0.94, 4.55	2.74	1.21, 6.23	8.3	0.56	0.13, 2.36		
	p trend		0.08					0.58			
IPAQ sitting	T1	13.8	1.00	Referent	Not retained		12.5	1.00	Referent	Not retained	
	T2	14.3	1.04	0.44, 2.43			18.6	1.60	0.47, 5.43		
	T3	16.3	1.21	0.53, 2.76			12.8	1.03	0.27, 3.91		
	p trend		0.65					0.96			

IPAQ = International Physical Activity Questionnaire; POR = prevalence odds ratio; CI = confidence interval

[a]Adjusted for other sedentary behavior measure

Appendix 11. Associations between C-reactive protein and measures of sedentary behavior by gender

		Female					Male				
			Unadjusted		Adjusted[a]			Unadjusted		Adjusted[a]	
Measure		%	POR	95% CI	POR	95% CI	%	POR	95% CI	POR	95% CI
Television viewing	T1	10.5	1.00	Referent	1.00	Referent	16.0	1.00	Referent	Not retained	
	T2	15.4	1.55	0.67, 3.62	1.41	0.60, 3.35	18.9	1.23	0.40, 3.77		
	T3	21.9	2.39	1.03, 3.52	2.28	0.98, 5.28	19.4	1.27	0.41, 3.91		
	p trend		0.04					0.67			
IPAQ sitting	T1	14.9	1.00	Referent	Not retained		10.0	1.00	Referent	Not retained	
	T2	11.9	0.77	0.32, 1.85			20.9	2.38	0.66, 8.65		
	T3	17.4	1.21	0.54, 2.68			23.1	2.70	0.73, 9.93		
	p trend		0.65					0.13			

IPAQ = International Physical Activity Questionnaire; POR = prevalence odds ratio; CI = confidence interval

[a]Adjusted for other sedentary behavior measure

Appendix 12. Associations between Pathobiological Determinants of Atherosclerosis in Youth risk score and measures of sedentary behavior by gender

		Female					Male				
			Unadjusted		Adjusted			Unadjusted		Adjusted	
Measure		%	POR	95% CI	POR	95% CI	%	POR	95% CI	POR	95% CI
Television viewing	T1	13.7	1.00	Referent	Not retained		18.0	1.00	Referent	Not retained	
	T2	14.1	1.03	0.46, 2.35			10.8	0.55	0.15, 1.98		
	T3	15.6	1.17	0.50, 2.73			19.4	1.10	0.36, 3.31		
	p trend		0.73					0.94			
IPAQ sitting	T1	14.9	1.00	Referent	Not retained		7.5	1.00	Referent	1.00	Referent
	T2	15.5	1.05	0.46, 2.38			23.3	3.74	0.91, 15.38	3.65	0.92, 14.44
	T3	12.8	0.84	0.36, 1.97			15.4	2.24	0.51, 9.89	2.12	0.49, 9.18
	p trend		0.7					0.33			

IPAQ = International Physical Activity Questionnaire; POR = prevalence odds ratio; CI = confidence interval

Appendix 13. Physical activity principal component factor loadings for females

Measure	Light/moderate lifestyle	Recreation/ vigorous	Mild/moderate exercise	Objectively measured
NL- 1000 steps	0.07	0.20	0.08	0.92
NL- 1000 activity minutes	-0.001	0.16	0.09	0.93
Godin total	0.08	0.54	0.78	0.17
Godin mild	0.20	-0.03	0.83	0.04
Godin moderate	0.11	0.25	0.78	0.07
Godin vigorous	-0.01	0.82	0.20	0.22
IPAQ total	0.81	0.51	0.14	0.10
IPAQ walk	0.87	0.03	0.12	0.12
IPAQ moderate	0.75	0.30	0.17	-0.20
IPAQ vigorous	0.25	0.85	0.12	0.17
IPAQ work	0.63	-0.17	0.23	-0.11
IPAQ domestic	0.68	0.21	0.09	-0.16
IPAQ travel	0.81	0.05	0.02	0.21
IPAQ recreation	0.20	0.90	0.14	0.12

NL = New Lifestyles; IPAQ = International Physical Activity Questionnaire

Appendix 14. Physical activity principal component factor loadings for males

Measure	Recreation/ vigorous	Work/travel	Mild/moderate exercise	Moderate lifestyle	Objectively measured
NL- 1000 steps	0.12	0.14	0.09	-0.06	0.92
NL- 1000 activity minutes	0.01	0.07	0.01	-0.07	0.95
Godin total	0.39	-0.10	0.86	0.10	0.11
Godin mild	-0.04	0.15	0.89	0.07	0.04
Godin moderate	0.07	0.001	0.83	0.20	-0.01
Godin vigorous	0.72	-0.25	0.26	0.03	0.20
IPAQ total	0.63	0.61	0.07	0.45	0.03
IPAQ walk	0.06	0.91	-0.01	0.14	0.15
IPAQ moderate	0.28	0.32	0.18	0.81	-0.12
IPAQ vigorous	0.93	0.17	0.10	0.03	0.05
IPAQ work	0.24	0.74	0.10	-0.19	0.02
IPAQ domestic	0.07	0.004	0.13	0.93	-0.07
IPAQ travel	-0.03	0.75	-0.03	0.28	0.17
IPAQ recreation	0.81	0.14	0.09	0.29	0.02

NL = New Lifestyles; IPAQ = International Physical Activity Questionnaire