TOWARD IMPROVEMENT OF OBJECTIVELY MEASURED SEDENTARY BEHAVIOR IN A FREE-LIVING ENVIRONMENT

by

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I dedicate this dissertation to my wife Eunyoo Choi
for her sacrifice and love throughout my journey to this point.

She has constantly motivated and encouraged me
to dream bigger dreams than I ever thought possible
since the moment we first met in 2005.

I could not have made this journey without her love and support.

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ABSTRACT

The objective of this dissertation was to extend our understanding of the objectively measured sedentary behavior (SB) and to explore ways to improve measurement practices of SB in health outcome research. The primary aim of the first study was to explore the measurement issues in objectively measured SB using the National Health Nutrition Examination Survey 2003-2005. The specific aims addressed were 1) the influence of duration of sedentary bout on the association of sedentary time with metabolic risk factors; and 2) the appropriateness of extracting sedentary breaks by counting the number of transitions from sedentary to active phase from accelerometer data. The findings highlighted that the sedentary time with relatively short bout (i.e., ≤ 10 minutes) was in general beneficially associated with health outcomes, which, in turn, had influenced on the dose-response relationships between total sedentary time with health outcomes. Another important finding was that the absolute number of sedentary breaks has a limited measurement property that may not be considered as the interruption of sedentary time, but rather it is related to the patterns of sedentary time accumulation.

The primary aim of the second study was to examine the validity of different types of objective monitoring devices for the assessment of SB in a free-living setting. The specific focus was placed on 1) the overall performance of three accelerometers (Actigraph GT3X, activPal, and Sensewear^{TM} Armband) to identify SB in a free-living setting; 2) the influence of sedentary bout restrictions on the validity of the devices to identify the structured SB at given bout condition; and 3) to develop the algorithm to identify SB-bout that may be feasible to identify the sedentary breaks congruent with what has been defined at the conceptual level. The results highlighted that the activPal is

the most accurate and precise measure of SB compared with a proxy of direct observation. One possible strategy to improve the performance of threshold-based GT3X measures could be the restriction of short sedentary bout. The developed algorithm was significantly influenced by the functional capability of devices to detect the postural information, and the activPal was the one that can be of useful when using the algorithm to identify the SB-bout.

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CHAPTER I

INTRODUCTION

Physical activity is one of the leading health behaviors in modern society with increased evidence of beneficial associations with various health outcomes (Haskell et al., 2007; Shiroma & Lee, 2010). In response to growing demands for promoting physical activity at individual- and population-levels, the U.S. Department of Health and Human Services (USDHHS) issued the first-ever Surgeon General's report (USDHHS, 1996), particularly focusing on physical activity in relation to health. The report suggested that all Americans should engage in regular moderate-intensity physical activity at least 30 minutes most days of the week (USDHHS, 1996). More recently, *the 2008 Physical Activity Guidelines for Americans* (USDHHS, 2008) was published as a result of continuous efforts to provide better physical activity guidelines for different age groups. The guidelines recommended for adults to engage in at least 150 minutes of weekly moderate-intensity physical activity, or 75 minutes of weekly vigorous-intensity physical activity, or an equivalent combination of weekly physical activity for both intensity levels, in order to experience substantial health benefits.

Motivated by the physical activity guidelines (USDHHS, 1996, 2008), great attention has been given to better characterizing a physical activity-related health risk group by emphasizing their levels of moderate- to vigorous-intensity physical activity. Particularly, a person with insufficient moderate- to vigorous-intensity physical activity who did not meet the physical activity guidelines has been considered as being sedentary (USDHHS, 1996), under the assumption that sedentary behavior (SB) and moderate- to vigorous-intensity physical activity are the opposite ends of the same activity continuum (Marshall & Merchant, 2013).

Recently, there has been a challenging debate on this assumption, and systematic efforts have been made to distinguish SB from the lack of moderate- to vigorous-intensity physical activity (i.e., physically inactive). Owen and colleagues (2000) published the first review article that systematically examined the possibility of distinct determinants of SB compared to physical activity. Over the past 10 years, an increased number of studies have begun focusing on SB as a distinct health risk behavior (Bankoski et al., 2011; Healy, Matthews, Dunstan, Winkler, & Owen, 2011), and it has now been well conceptualized with its own definition separated from the physically inactive.

SB is defined as a prolonged sitting or reclining posture that requires low levels of energy expenditure ranging from 1.0 to 1.5 metabolic equivalent units (METs) (Owen, Healy, Matthews, & Dunstan, 2010; Pate, O'Neill, & Lobelo, 2008). The common types of SB may involve various forms of screen-based activities such as watching TV, working on a computer, playing a video game etc., or sitting-based transportation activities such as driving a car. Emerging evidence revealed deleterious associations of various types of SB with health outcomes. Recent population-based studies have shown that the increased time spent in SB is strongly associated with cardio-metabolic biomarkers and with the risk of developing metabolic syndrome among adults (Bankoski et al., 2011; Healy et al., 2011; Wijndaele et al., 2010). Furthermore, prospective studies revealed a greater hazard to all-cause and cardiovascular mortality as a consequence of increased time spent in SB (Katzmarzyk & Lee, 2012; Wijndaele et al., 2011). As an increasing awareness in recent years of the vital role of SB in relation to public health, there has been a huge demand for better characterizing and measuring SB in a free-living environment (Atkin et al., 2012; Marshall & Merchant, 2013).

Similar to physical activity measurements, SB measurements involve subjective and objective methods. Subjective measures of SB such as self- and proxy-report questionnaires and diaries have been extensively used in large-scale observational studies (Sugiyama, Healy, Dunstan, Salmon, & Owen, 2008; Wijndaele et al., 2011). The subjective methods have been recommended as cost-effective methods to assess SB in a free-living environment, which also have a unique strength for quantifying time spent in SB in a specific context (e.g., screen time, work-related sitting time, etc.). However, measurement properties (i.e., reliability and validity) of subjective methods are still questionable (Atkin et al., 2012), with the same methodological limitations frequently reported for subjective measures of physical activity (e.g., recall bias, under- or over-estimation, etc.) (Macera et al., 2001).

Objective measure of SB is a relatively new scientific area, which has been developed in accordance with technological advancement in recent years. The types of objective measures of SB can be broadly categorized into two families, energy expenditure devices and posture classification devices, based on how they classify or capture SB (Granat, 2012). Energy expenditure devices, which generally refer to accelerometers, measure the frequency and amplitude of accelerations generated by ambulatory movement in a certain time interval and provide such information in the form of activity counts (Atkin et al., 2012). Different thresholds of activity counts that correspond to energy expenditures of different intensity levels of physical activity have been developed mostly in laboratory-based calibration studies across different manufactures (Freedson, Melanson, & Sirard, 1998; Matthews, 2005). Unlike the energy expenditure classification devices that require certain thresholds of activity counts to assess SB, posture classification devices measure absolute body positions or status of human movement and provide outputs into four types of activities (i.e., lying, sitting, standing, and walking) for a pre-defined time interval (Grant, Ryan, Tigbe, & Granat, 2006). Objective measures of SB have been increasingly used as they allow researchers to obtain valid and reliable estimates of time spent in SB in a free-living environment compared to subjective measures of SB (Atkin et al., 2012; Healy et al., 2011).

Statement of the Problem

Despite the promising aspects of objective measures of SB, there remains significant room for improvement in measuring SB in a free-living environment. Of the several key issues in using objective measures of SB, which may include but not limited to, device initialization, appropriateness of activity counts threshold for SB, and signal feature extraction, etc., (Crouter, Dellavalle, Haas, Frongillo, & Bassett, 2013; Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011; Wanner, Martin, Meier, Probst-Hensch, & Kriemler, 2013), one crucial issue raised in the literature is that both types of SB monitoring devices have limited functional abilities for measuring SB in accordance with the conceptual definition of SB (Marshall & Merchant, 2013). This may lead to biased estimates of time spent in SB in a free-living environment. For instance in one of the widely used energy expenditure devices, Actigraph accelerometer (Actigraph, LLC, Pensacola, FL, USA), activity counts <100 cpm has been extensively used to identify the SB; however, the activities that featured activity counts <100 cpm may include quiet standing or some light-intensity activities in a standing position (Granat, 2012; Marshall & Merchant, 2013). Conversely, ActivPal, which is a posture classification device, ignores the definition regarding energy expenditure (<1.5 METs) in measuring the SB.

There have been continuous efforts to address measurement limitations of SB associated with the functional abilities of objective monitoring devices; however, one aspect that has been underestimated in the efforts to improve the measurement practice of objective measures of SB is the duration of SB, represented by the '*prolonged*' concept in the SB definition. For example, the typical data processing strategy to convert raw Actigraph accelerometer data to sedentary time is to count every single minute with activity counts <100 cpm regardless of the continuous sedentary bout (Matthews et al., 2008). Likewise, the activPal provides information of body position or status by 1- through 100-seconds intervals, in which total time spent in SB is the summation of time intervals that featured a sitting/lying position (Granat, 2012).

To the best of my knowledge, there are few relevant studies that fully addressed the data processing issues, particularly focusing on sedentary duration or bout, in converting raw time-stamped accelerometer data to SB indicators. Given the overwhelming interest in SB as an independent health risk behavior in health outcome research, there is a strong need for a better understanding of SB and to improve the measurement properties of objective measures of this behavior.

Statement of the Purpose

The overarching goal of this project is to extend our understanding of SB and to improve the measurement practice of objective measures of SB in a free-living environment. Specifically, the purposes of the first study is to address the measurement issues in objectively measured SB, particularly focusing on sedentary bouts in relation to health outcomes, using the accelerometer data obtained from a large national representative sample of the US adults. The contemporary measurement issues in objectively measured SB with specific emphasis on 1) sedentary bout duration; and 2) breaks in sedentary time will be discussed. The findings from the first study led to the second study that aimed 1) to examine the validity of different types of SB monitoring devices in a free-living environment against a proxy of direct observation; and 2) to develop a new algorithm that identifies SB-bout that may include time intervals for structured SB in addition to the possible sedentary breaks. These two studies combined will allow better understanding of the measurement issues in objectively measured SB in physical activity research.

CHAPTER II

EXTRACTING THE OBJECTIVELY MEASURED SEDENTARY BEHAVIOR FROM ACCELEROMETER DATA: MEASUREMENT CONSIDERATIONS FOR SURVEILLANCE AND RESEARCH APPLICATIONS

Introduction

The health benefits of physical activity (PA) are well established (USDHHS, 2008) but a paradigm shift in the physical activity field is now challenging researchers to think about the independent effects of sedentary behavior (SB). This shift evolved from a rapidly growing body of evidence indicating that SB may contribute to individual health risks even if people are physically active (Hamilton, Healy, Dunstan, Zderic, & Owen, 2008; Owen, Leslie, Salmon, & Fotheringham, 2000). A challenge in advancing research in this area is, however, the lack of clear operational guidelines to define SB. According to Owen, Bauman, and Brown (2009), SB refers to "*. . . behaviours for which energy expenditure is low, including prolonged sitting time in transit, at work, at home and in leisure time" (p. 82)*. The Sedentary Behavior Research Network has also proposed definitions of SB that capture both posture (i.e., sitting/reclining) and low levels of energy expenditure (1.0 to 1.5 METs) (Sedentary Behavior Research Network, 2012). These distinctions make conceptual sense to characterize SB as being distinct from physically inactive (Owen, Healy, Matthews, & Dunstan, 2010; Pate, O'Neill, & Lobelo, 2008) but have proven difficult to operationalize – particularly by researchers using objective monitors such as the Actigraph since postures cannot be readily determined. In this case, it is not possible to distinguish light-intensity physical activity (e.g., standing still) from SB (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011; Lyden, Kozey-Keadle, Staudenmayer, & Freedson, 2012).

This is an inevitable limitation when studying SB, another issue that has received relatively little attention is how to quantify the duration of SB. A major context of SB (e.g., watching TV, working on a computer, driving a car, etc.) may significantly involve a prolonged time span, and sedentary time has been conceptually defined as the time spent in SB that is predominated by prolonged sitting with lower energy expenditure (Owen et al., 2010); however, the vast majority of the literature has relied on relatively short time scale when extracting sedentary time from raw accelerometry data. For instance, one widely used approach to describe sedentary time from Actigraph accelerometry data is to count every *single minute* or even shorter (e.g., 10 seconds) where activity counts are less than the threshold for SB (Clark et al., 2011; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Lynch et al., 2010; Lynch et al., 2011; Maher, Mire, Harrington, Staiano, & Katzmarzyk, 2013). This method does not take the *prolonged* aspect of the definition into account. One study (Bankoski et al., 2011) that examined the association of SB with metabolic syndrome using NHANES 2003-2006 accelerometry data operationally defined the sedentary bout as a period of time >5 minute with activity counts <100 cpm with 1 allowable minute outside the threshold; however, there is still little evidence for imposing the sedentary time >5 minutes to reflect the prolonged sedentary time that may be deleteriously associated with health outcomes.

On the other hand, a seminal finding in the literature demonstrated that breaks in sedentary time (defined as interruptions in sedentary time) could explain differences in cardio-metabolic and inflammatory risk biomarkers (Healy et al., 2008; Healy, Matthews, et al., 2011). The authors implied that people who engaged in the same overall amount of sedentary time could have experienced distinct health-related issues depending on how their sedentary time was accumulated. This finding sparked considerable interest in the study of SB as it demonstrated that *breaking up prolonged sedentary time* needs to be factored into evaluations of health risk as well as interventions designed to change behavior (Dunstan, Healy, Sugiyama, & Owen, 2010; Owen et al., 2010). However, similar methodological challenges still remain due to the difficulty to capture postural changes using accelerometers (e.g., Actigraph). Furthermore, there has been a lack of clear and understandable guidelines to operationalize breaks in sedentary time from accelerometry data. Healy et al. (2008) first described breaks in sedentary time as an absolute number of transitions from sedentary to active phase; however, this approach has been questioned due to ambiguity of its measurement property (Healy, Matthews, et al., 2011; Lyden et al., 2012) and has led the researchers to wonder if it is a pattern of how sedentary time is accumulated or global measure of breaks as it may indicate physical activity which may matter for health (Colley et al., 2013; Saunders et al., 2013).

The present study fills that gap by examining the impact of sedentary time and breaks captured using different bout durations. The specific purposes were: 1) to examine the accrued patterns of sedentary time and breaks; and 2) to evaluate the sedentary time and breaks in different bout durations in relation to health outcomes, including cardiovascular risk factors. The study is directly responsive to recommendations for continued research on definitions and measurement of SB (Matthews, Hagströmer, Pober, & Bowles, 2012). Specifically, examining sedentary bouts of varying duration in relation to health biomarkers would extend our practical understanding of SB which should be targeted (Owen, 2012) that may be of beneficial to operationalize the sedentary time and breaks from accelerometry data in future research.

Methods

Survey Data and Study Sample

The data for the present study were obtained from the NHANES 2003-2004 and 2005-2006. The NHANES dataset provides cross-sectional data for a national representative sample of the US civilian non-institutionalized population selected by a complex multistage probability sampling scheme. The survey measured broad areas of health-related outcomes through household interviews and physical examinations at the mobile examination center (MEC).

Among participants who visited the MEC, all ambulatory participants (≥ 6 years) were eligible for accelerometer measures. The Actigraph accelerometer (model 7164) was used to obtain objective measures of physical activity. Participants were instructed to wear the accelerometer on their right hip during waking hours across 7 consecutive days, with the exception of when engaging in any water-based activities (e.g., bathing or swimming). Activity counts that represent integrated acceleration information of ambulatory movements were recorded in minute-by-minute intervals. A detailed description of the NHANES data can be found at www.cdc.gov/nchs/nhanes.htm.

A total of 9,151 adults (≥18 years) provided accelerometer data. After excluding those with missing values for one or more of the cardiovascular risk factors (with an exception of fasting sub-component, TG) or covariates examined in this study, or with insufficient valid accelerometer data (refer to later section), the final sample consisted of 5,917 adults (2,941 male and 2,976 female) which included a fasting sub-sample of 2,663 who provided a TG measure.

Table 1
Descriptive Statistics of Outcome Variables across Demographic Characteristics among US Adults

	% (*SE*)	Waist Circumference (cm)	HDL-C (mg/dL)	BMI (kg/m^2)	MVPA (mins·day $^{-1}$)	Fasting sub-sample % (*SE*)	Fasting sub-sample Triglycerides (mg/dL)
Total	(*n* = 5,917)	95.43 (.40)	54.36 (.32)	27.75 (.17)	7.38 (.37)	(*n* = 2,667)	144.37 (3.35)
Gender							
Male	48.43 (.61)	98.30 (.53)	48.52 (.32)	27.63 (.19)	9.00 (.47)	48.90 (1.02)	158.50 (3.85)
Female	51.57 (.61)	92.73 (.50)	59.85 (.49)	27.87 (.23)	5.86 (.35)	51.70 (1.02)	131.17 (4.29)
Race							
Non-Hispanic White	71.17 (2.23)	96.15 (.48)	54.29 (.36)	27.66 (.20)	7.06 (.44)	73.25 (2.37)	147.15 (4.32)
Non-Hispanic Black	11.93 (1.63)	96.12 (.63)	57.70 (.74)	29.43 (.26)	7.52 (.57)	10.02 (1.33)	112.85 (3.05)
Mexican American	8.34 (1.12)	94.13 (.65)	51.15 (.50)	27.73 (.24)	8.91 (.57)	7.97 (1.18)	160.90 (.8.29)
Other Hispanic/races	8.57 (.84)	89.76 (.99)	53.47 (.91)	26.26 (.43)	8.32 (1.03)	8.76 (1.06)	142.01 (7.60)
Income							
<$15k	13.78 (.91)	93.19 (.85)	53.44 (.84)	27.27 (.37)	8.86 (.88)	10.44 (.71)	150.76 (8.49)
$15k-34.9k	25.33 (1.07)	95.18 (.72)	54.90 (.56)	27.50 (.25)	6.00 (.42)	24.73 (1.10)	149.16 (9.16)
35k-64.9k	28.21 (1.10)	96.74 (.58)	53.26 (.49)	28.26 (.22)	7.04 (.59)	29.27 (1.39)	145.15 (4.63)
≥$65k	32.69 (1.76)	95.42 (.61)	55.29 (.41)	27.72 (.26)	8.12 (.44)	35.56 (1.96)	138.53 (3.69)

Note. All values are the survey-weighted means (standard error) unless otherwise specified
HDL-C = high-density lipoprotein cholesterol; BMI = body mass index; MVPA = moderate-to-vigorous-intensity physical activity

Accelerometry-based SB Measures

An automated SAS macro provided by NCHS was used for quality control and to identify non-wear times. Non-wear time is defined as intervals of at least 60 minutes of 0 activity counts (i.e., no movement), with allowance for up to 2 consecutive minutes of activity counts between 0 and 100 (Troiano et al., 2008). After removing non-wear times from raw accelerometer data, the following SB parameters were extracted for each measurement day using the traditional algorithms as previously described in the literature (Healy et al., 2008; Matthews et al., 2008):

1) sedentary time – a minute where activity counts are <100 cpm;
2) sedentary break – a transition point from a sedentary (<100 cpm) to active phase (≥100 cpm);
3) sedentary bout – a duration of continuous sedentary time (i.e., sedentary event);
4) mean intensity – the average activity counts within each sedentary bout.

In addition, because we aimed to explore accrued patterns of sedentary time and breaks, particularly focusing on sedentary bout durations, all SB measures were extracted within the respective bout durations of 1-min, 2-4 min, 5-9 min, 10-14 min, 15-19 min, 20-24 min, 25-29 min, and ≥30-min in addition to total accrued quantities.

All SB measures obtained for each measurement day were then averaged across only valid days (i.e., 10 or more hours of wear time), to represent the average measures of SB per day. Participants with 4 or more valid days are included in the analysis. In addition, because sedentary time or breaks are influenced by accelerometer wear times (Matthews et al., 2008), the least-square adjustment for wear times was made for all SB measures using the residuals obtained from linear regression models where SB measures were regressed on wear times (Healy, Matthews, et al., 2011; Willett, Howe, & Kushi, 1997).

Cardiovascular Risk Factors and Other Covariates

The primary purpose of this study was to evaluate the impact of different measures of sedentary time on health outcomes after taking sedentary bout durations into account. In this case, stronger associations with health outcomes would be expected for approaches that most effectively capture SB. Three measures of cardiovascular risk factors, which include triglyceride (TG) (mg/dL), waist circumference (WC) (cm), and high-density lipoprotein cholesterol (HDL-C) (mg/dL), were obtained as these are evident to be significantly associated with SB measures in recent studies that used the NHANES data (Bankoski et al., 2011; Healy, Matthews, et al., 2011). In addition, body mass index (BMI) (kg/m^2) was also obtained as there is still controversy in regards to its relationship with SB measures in the NHANES data (Maher et al., 2013).

The average time spent in moderate-to-vigorous-intensity physical activity (MVPA), based on a modified 10-min bout condition (i.e., a minimum of 8 out of 10 consecutive minutes of MVPA), across valid days was obtained from raw accelerometer data using the threshold of ≥2020 cpm (Troiano et al., 2008). Demographic characteristics of the participants including age (years), sex, race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Mexican American, and Other Hispanic/other races), and family income (<$15k, $15k-34.9k, $35k-64.9k, ≥$65k) were also used as covariates in the statistical model (See Table 1 for descriptive statistics).

Statistical Analyses

To explore the accumulation patterns of SB measures, descriptive statistics as well as the proportions (%) of accrued sedentary time and breaks within each bout duration were estimated. Univariate normality of sedentary time and breaks within each bout duration were examined by the skewness and kurtosis statistics in order to assure the use of parameterized linear models for sequential steps.

To evaluate the measurement properties of accrued sedentary time and breaks across a set of bout durations, bivariate correlation analyses with total sedentary time and breaks were performed using a mean of uncorrected item-total correlation analysis. Item-total correlation analysis is a well-known statistical approach for evaluating the construct validity of measurement at the item level (Nunnally, Bernstein, & Berge, 1967). In this study, we assumed that the sedentary times and breaks within each bout duration were the sub-items that consisted of total sedentary time and breaks, respectively. A positive and relatively high correlation coefficient of ≥.40 (Nunnally et al., 1967) was expected for each of the correlation analyses. In addition, bivariate correlation analyses for pairs of sedentary time and breaks at each bout duration were conducted as the secondary analysis to aid in better understanding of the practical significance of sedentary breaks after taking bout durations into account.

Lastly, separate linear regression models were fitted for each bout duration in order to evaluate the measurement properties of sedentary time and breaks within each bout duration in relation to cardiovascular risk factors after controlling for covariates. In this analysis, total sedentary time or breaks were not adjusted in each regression model due to the fact that the separate independent associations of the sub-components of total measure with the dependent variable may be unreliably estimated when total measure is adjusted in the model (Satia-Abouta et al., 2003; Wacholder et al., 1994).

All statistical analyses were performed using SURVEY procedures in SAS v9.3 (SAS Institute Inc, Cary, NC) to account for the complex sampling designs in the NHANES. Four-year sample weights were calculated using the 2-year sample weights of the NHANES 2003-2004 and 2005-2006 cycles. To account for a selection bias by inclusion criteria of this study, 4-year sample weights were recalculated based on sample weights in the raw NHANES 2003-2006 data after taking age, gender, and racial/ethnic groups into account. For the analyses of fasting sub-component measure [i.e., TG], four-year fasting sub-sample weights were used. A prior significance level was set at $p < .05$ for all statistical analyses.

Results

Descriptive statistics for accrued SB measures are presented in Table 2. US adults spent an average of 482.88 minutes per day in sedentary time, which were accumulated over 93.02 sedentary bouts. A majority of sedentary times was observed within bout durations of <10 minutes (1-min = 36.30%, 2-4 min = 33.27%, and 5-9 min = 15.53%). Similarly, of the 92.41 total sedentary breaks, a majority of sedentary breaks were also detected within bout durations of 1-min (36.54%), 2-4 min (33.65%), and 5-9 min (15.56%).

Bivariate correlation analyses of sedentary time and bout durations revealed negative relationships for durations of 1-min and 2-4 min (r = -.64 and r = -.24, respectively) and a positive relationship for durations of 5-9 min (r = .35). In contrast, consistently strong positive relationships were found between sedentary breaks and each of the bout duration indicators (1-min: r = .80, 2-4 min: r = .94, and 5-9 min: r = .61).

The results of the regression analyses are presented in Table 3. Overall, total sedentary time was deleteriously associated with all health outcomes (WC: b = .005, p =.049; HDL-C: b = -.012, p <.001; TG: b = .113, p <.001) with an exception of BMI (b = .001; p = .521). However, separate regression analyses across bout durations revealed mixed associations with health outcomes. Specifically, sedentary time at bout durations of 1-min, 2-4 min, or 5-9 min were beneficially associated with WC (1-min: b = -0.189, p <.001; 2-4 min: b = -0.083, p <.001; 5-9 min: b = -0.032, p = .003), HDL-C (1-min: b = .111, p <.001), TG (1-min: b = -1.136, p <.001), and BMI (1-min: b = -0.056, p <.001; 2-4 min: b = -0.025, p <.001; 5-9 min: b = -0.014, p = .004). Sedentary times at bout durations of ≥ 10-14 min and ≥ 5-9 min were deleteriously associated with WC (all p's < .05) and HDL-C (all p's < .05), respectively.

Table 2

Accelerometer Determined Sedentary Behavior Measures across the Bout Durations (n = 5,917)

	Total	Sedentary bout durations							
		1-min	2-4 min	5-9 min	10-14 min	15-19 min	20-24 min	25-29 min	≥30-min
Sedentary times									
Mean (*SE*) min·day $^{-1}$	482.88 (1.93)	34.25 (.17)	84.96 (.41)	94.04 (.33)	62.45 (.34)	44.47 (.28)	33.36 (.28)	25.69 (.26)	103.66 (1.30)
% (SE)	-	8.12 (.06)	19.21 (.12)	20.19 (.08)	12.89 (.06)	8.91 (.05)	6.58 (.05)	4.95 (.04)	19.16 (.19)
Correlation with total sedentary time [a]	-	-.64	-.24	.35	.65	.70	.69	.66	.77
Sedentary breaks									
Mean (*SE*) break·day $^{-1}$	92.41 (.31)	34.06 (.17)	31.43 (.16)	14.35 (.05)	5.30 (.03)	2.62 (.02)	1.50 (.01)	0.93 (.01)	2.21 (.03)
% (SE)	-	36.54 (.10)	33.65 (.07)	15.56 (.05)	5.87 (.04)	2.95 (.02)	1.72 (.02)	1.08 (.07)	2.62 (.04)
Correlation with total sedentary breaks [b]	-	.80	.94	.61	.04	-.19	-.33	-.40	-.60
Correlation between sedentary time and breaks [c]	-.23	1.00	.99	.99	1.00	1.00	.99	.99	.97
Sedentary bouts									
Mean (*SE*) bout·day $^{-1}$	93.02 (.31)	34.25 (.17)	31.53 (.16)	14.41 (.05)	5.34 (.03)	2.65 (.02)	1.53 (.01)	0.96 (.01)	2.35 (.03)
% (SE)	-	36.30 (.10)	33.27 (.07)	15.53 (.05)	5.96 (.03)	3.04 (.02)	1.80 (.02)	1.15 (.01)	2.96 (.04)
Average intensity during sedentary time									
Mean (*SE*) cpm·day $^{-1}$	30.43 (.11)	42.17 (.14)	30.77 (.11)	20.40 (.10)	14.51 (.09)	11.54 (.08)	9.55 (.07)	8.27 (.07)	6.02 (.07)

Note. All estimates were adjusted for accelerometer wear time

SE = standard error; CPM = counts per minute

[a] correlation coefficients between sedentary time in each bout duration and total sedentary time

[b] correlation coefficients between sedentary breaks in each bout duration and total sedentary breaks

[c] correlation coefficients between the pairs of sedentary time and breaks within each bout duration

Pertaining to sedentary breaks, total sedentary breaks was positively associated with WC (b = -0.124, p <.001) and BMI (b = -0.040, p <.001). However, similar to sedentary time, counterintuitive associations of sedentary breaks with health outcomes were also detected after taking bout durations into account. For instance, the significant associations of sedentary breaks with decreased level of WC were detected at bout durations of <10-14 min (1-min: b = -0.188, p <.001; 2-4 min: b = -0.226, p <.001; 5-9 min: b = -0.241, p = .002) while opposite associations were detected at remaining longer bout durations where the sedentary breaks were significantly associated with increased level of WC (all p's < .05). Moreover, although there were insignificant associations of total sedentary breaks with HDL-C (b = 0.028, p = .141) and TG (b = -0.099, p = .675), sedentary breaks at bout duration of 1-min was significantly and positively associated with HDL-C (b = 0.111, p <.001) and TG (b =-1.141, p <.001), and again, deleterious associations were detected for the remaining longer bout durations.

To extend the understanding of the influence of bout durations on the relationship with health outcomes, we created two sets of composite variables for sedentary time and breaks based on the thresholds of <5-min and <10-min bout durations. The bivariate correlation analyses for pairs of sedentary time and breaks showed relatively high inter-relationships for both lengths (r's = .973 and .772 for 5-min criterion; r's = .883 and .923 for 10-min criterion) (see Table 4). The separate regression analyses using new composite variables showed consistent trends where the implications of the relationships of sedentary time and breaks with health outcomes tended to be differentiated by the thresholds of bout durations (Table 5). For instance of 5-min criterion, sedentary time at <5-min was beneficially associated with decreased level of

WC (*b* = -0.068, *p* <.001) while sedentary time at ≥5-min was significantly associated with increased level of WC (*b* = 0.044, *p* = .293).

Table 3

Associations of Accelerometer Determined Sedentary Behavior Measures with Health Outcomes across the Bout Durations (n = 5,917)

	Mean (SE)	Waist Circumference (cm)		HDL-C (mg/dL)		Triglyceride[a] (mg/dL)		BMI (kg/m^2)	
		b (SE)	*p*-value	*b (SE)*	*p*-value	*b (SE)*	*p*-value	*b (SE)*	*p*-value
Sedentary time									
Total	482.88 (1.93)	0.005 (.00)	.049*	-0.012 (.00)	<.001*	0.113 (.03)	<.001*	0.001 (.00)	.521
Bout durations									
1-min	34.25 (.17)	-0.189 (.03)	<.001*	0.111 (.03)	<.001*	-1.136 (.26)	<.001*	-0.056 (.01)	<.001*
2-4 min	84.96 (.41)	-0.083 (.02)	<.001*	0.021 (.01)	.102	-0.044 (.16)	.786	-0.025 (.01)	<.001*
5-9 min	94.04 (.33)	-0.032 (.01)	.003*	-0.024 (.01)	.032*	0.545 (.25)	.035*	-0.014 (.01)	.004*
10-14 min	62.45 (.34)	0.034 (.01)	.023*	-0.054 (.01)	<.001*	0.730 (.20)	.001*	0.007 (.01)	.198
15-19 min	44.47 (.28)	0.038 (.01)	.006*	-0.050 (.01)	.002*	0.440 (.12)	.001*	0.009 (.01)	.092
20-24 min	33.36 (.28)	0.040 (.02)	.036*	-0.041 (.02)	.010*	0.379 (.14)	.009*	0.008 (.01)	.229
25-29 min	25.69 (.26)	0.050 (.02)	.009*	-0.046 (.02)	.016*	0.549 (.15)	.001*	0.012 (.01)	.088
≥30-min	103.66 (1.30)	0.013 (.00)	.001*	-0.012 (.00)	.007*	0.053 (.05)	.282	0.003 (.00)	.043*
Sedentary breaks									
Total	92.41 (.31)	-0.124 (.02)	<.001*	0.028 (.02)	.141	-0.099 (.23)	.675	-0.040 (.01)	<.001*
Bout durations									
1-min	34.06 (.17)	-0.188 (.03)	<.001*	0.111 (.03)	<.001*	-1.141 (.26)	<.001*	-0.056 (.01)	<.001*
2-4 min	31.43 (.16)	-0.226 (.04)	<.001*	0.066 (.04)	.074	-0.223 (.46)	.632	-0.067 (.02)	<.001*
5-9 min	14.35 (.05)	-0.241 (.07)	.002*	-0.136 (.07)	.063	3.207 (1.51)	.042*	-0.099 (.03)	.002*
10-14 min	5.30 (.03)	0.392 (.17)	.025*	-0.645 (.14)	<.001*	8.723 (2.47)	.001*	0.084 (.07)	.213
15-19 min	2.62 (.02)	0.625 (.23)	.001*	-0.814 (.25)	.003*	7.467 (2.10)	.001*	0.140 (.09)	.112
20-24 min	1.50 (.01)	0.894 (.41)	.037*	-0.924 (.35)	.012*	8.607 (2.92)	.006*	0.194 (.15)	.213
25-29 min	0.93 (.01)	1.345 (.51)	.013*	-1.337 (.48)	.010*	14.137 (4.07)	.002*	0.328 (.20)	.106
≥30-min	2.21 (.03)	0.704 (.19)	<.001*	-0.641 (.21)	.005*	2.806 (2.43)	.257	0.165 (.08)	.033*

Note. Separate regression analyses were conducted by each bout durations after adjusting for age, sex, race/ethnicity, family income, and MVPA min·day^{-1}.

HDL-C = high-density lipoprotein cholesterol; BMI = body mass index; * $p < .05$

[a]the estimates were based on the fasting sub-sample of 2,663 adults.

Discussion

The objective measured SB using accelerometers has been examined in relation to a variety of health outcomes. Although the body of literature has shown promising implications of reducing prolonged sedentary time and increasing sedentary breaks as they may provide potential health benefits, little attention has been given to the issues related to data processing of accelerometry data to operationalize SB parameters. In this study, we found two main issues in converting raw accelerometer data to SB parameters that are worth discussing.

How Long is the Minimum Sedentary Bout Duration to Define *Prolonged Sedentary Time*?

SB has been defined as any activity during waking hours that requires low energy expenditures of <1.5 MET, which typically involves prolonged sitting or a reclined posture such as watching TV, working on a computer, or driving a car (Owen et al., 2010; Pate et al., 2008). However, there has been a lack of clear definition regarding the minimum duration of sedentary bout that could potentially be considered as prolonged sedentary time, requiring more efforts to explore the accrued patterns of sedentary time in relation to health biomarkers.

The initial finding of the accrued patterns of sedentary time using single minute bout was that a majority of sedentary time had occurred within relatively short bout durations. Of 93.02 sedentary bouts, approximately 70% were attributed to the sedentary time that occurred at bout durations of <5-min (≈85% for <10-min), which accounted for approximately 27 % of total sedentary time (≈47% for <10-min). Furthermore, bivariate correlations analyses for pairs of sedentary times at bout durations of 1-min, 2-4 min, and 5-9 min with total sedentary time showed negative or relatively weak linear relationships (*r's* <.40). These findings imply that the sedentary times that last over relatively short durations may not represent the same measurement construct as the sedentary times at relatively long bout durations.

To further examine the significations of bout durations in objectively measured sedentary time, separate linear regression analyses were performed in relation to the health outcomes. Pertaining to total sedentary time, our findings are consistent with previous studies (Healy, Matthews, et al., 2011; Henson et al., 2013), where significant detrimental associations were observed with WC, HDL-C, and TG. Moreover, our result showing the insignificant relationship of total sedentary time with BMI was also consistent with a recent study (Maher et al., 2013) that used the same study sample. However, the implications of total sedentary time in relation to health outcomes were not constant after taking bout durations into account. The accrued sedentary times at bout durations of <5-min were beneficially associated with WC, HDL-C, and BMI as shown in Table 5. These results are in contrast to the current understanding of the deleterious associations of accrued sedentary time with health outcomes.

Table 4

Bivariate Correlation Matrix between Sedentary Time and Breaks across Different Bout Duration Conditions (n = 5,917)

		Sedentary Time			
	Mean (*SE*)	5-min criterion		10-min criterion	
		<5-min	≥5-min	<10-min	≥10-min
Mean (*SE*)		119.21(.56)	363.67 (2.08)	213.25 (.75)	269.2.02)
Sedentary breaks					
5-min criterion					
<5-min	65.49 (.32)	.973	-	-	-
≥5-min	26.92 (.10)	-	.772	-	-
10-min criterion					
<10-min	79.84 (.34)	-	-	.883	-
≥10-min	12.57 (.07)	-	-	-	.923

Table 5

Associations of Accelerometer Determined Sedentary Behavior Measures with Health Outcomes across Different Bout Duration Conditions (n = 5,917)

	Mean (SE)	Waist Circumference (cm)		HDL-C (mg/dL)		Triglyceride[a] (mg/dL)		BMI (kg/m^2)	
		b (SE)	*p*-value	*b (SE)*	*p*-value	*b (SE)*	*p*-value	*b (SE)*	*p*-value
Sedentary time									
Total	482.88 (1.93)	0.005 (.00)	.049*	-0.012 (.00)	<.001*	0.113 (.03)	<.001*	0.001 (.00)	.521
5-min criterion									
<5-min	119.21 (.56)	-0.068 (.01)	<.001*	0.024 (.01)	.019*	-0.157 (.11)	.160	-0.020 (.00)	<.001*
≥5-min	363.67 (2.08)	0.008 (.00)	.001*	-0.011 (.00)	<.001*	0.097 (.02)	<.001*	0.002 (.00)	.079
10-min criterion									
<10-min	213.25 (.75)	-0.039 (.01)	<.001*	0.003 (.01)	.593	-0.096 (.11)	.387	-0.013 (.00)	<.001*
≥10-min	269.63 (2.02)	0.010 (.00)	<.001*	-0.010 (.00)	<.001*	0.081 (.02)	.003*	0.002 (.00)	.024*
Sedentary breaks									
Total	92.41 (.31)	-0.124 (.02)	<.001*	0.028 (.02)	.141	-0.099 (.23)	.675	-0.040 (.01)	<.001*
5-min criterion									
<5-min	65.49 (.32)	-0.120 (.02)	<.001*	0.055 (.02)	.005*	-0.457 (.18)	.015*	-0.036 (.01)	<.001*
≥5-min	26.92 (.10)	0.044 (.04)	.293	-0.191 (.04)	<.001*	2.464 (.61)	<.001*	0.005 (.02)	.774
10-min criterion									
<10-min	79.84 (.34)	-0.113 (.02)	<.001*	0.041 (.02)	.019*	-0.261 (.19)	.176	-0.035 (.01)	<.001*
≥10-min	12.57 (.07)	0.250 (.07)	<.001*	-0.298 (.07)	<.001*	2.872 (.55)	<.001*	0.056 (.03)	.041*

Note. Separate regression analyses were conducted by each bout duration condition after adjusting for age, sex, race/ethnicity, family income, and MVPA min·day^{-1}.
HDL-C = high-density lipoprotein cholesterol; BMI = body mass index; * $p < .05$
[a]the estimates were based on the fasting sub-sample of 2,663adults.

One possible explanation which would support our findings may be related to the measurement system of the accelerometer used in NHANES. The Actigraph accelerometer used in NHANES is an energy classification device (Actigraph model 7164) that records the accelerations of ambulatory movements of the waist in forms of activity counts (Granat, 2012). An activity cutoff of <100 cpm has broadly been used for calibrating sedentary time in Actigraph accelerometer data with evidence of moderately high correlations in sedentary time between accelerometer and the Intelligent Device for Energy Expenditure and Activity monitor (Matthews et al., 2008); however, it has also been generally acknowledged that the energy classification devices may not be adequate to distinguish changes in posture (e.g., sitting vs. standing) (Granat, 2012; Kozey-Keadle et al., 2011). Specifically, activities that feature activity counts <100 cpm may include light-intensity physical activities in a standing position, such as washing dishes or folding laundry (Kozey, Lyden, Howe, Staudenmayer, & Freedson, 2010), which may have positive physiological effects by producing low levels of energy expenditure throughout the postural muscle activations (Hamilton et al., 2008). Thus, it is plausible to say that the minutes where the activity counts are <100 cpm and last for a relatively short duration may potentially include time spent in light-intensity physical activities, which in turn may positively influence on the health outcomes. However, it should also be noted that the average intensity during sedentary times at 1- and 2-4 min bout durations was 42.17 cpm (SE = .14) and 30.77 cpm (SE = .11), respectively, which were lower than the previously proposed SB thresholds of 150 cpm (Kozey-Keadle et al., 2011), 100 cpm (Matthews et al., 2008), or 50 cpm (Crouter, Dellavalle, Haas, Frongillo, & Bassett, 2013). This may imply that the beneficial associations of accrued sedentary time at short bout durations with health outcomes are not solely due to an inability to capture sitting posture by an energy classification device using <100 cpm as a threshold of sedentary.

While acknowledging the functional limitation of energy classification devices to discriminate sitting postures, it is also still questionable whether a short bout of sedentary time can be considered as a measure of the time spent in prolonged SB. The major context of SB (e.g., watching TV, driving a car, etc.) are predominated by prolonged sitting with low energy expenditure (Owen et al., 2010). However, relying on a single minute or shorter bout to estimate the time spent in SB from accelerometer data may significantly include time spent in *sporadic sedentary behavior* but not necessarily *prolonged sedentary behavior*. For example, people may take a few minute breaks in a sitting position during an exercise session and it may not be legitimate to consider this short break time as the time spent in *prolonged sedentary behavior*.

Using shorter epochs or intervals in summarizing accelerometer data would provide better descriptions of the continuity of human movement in a free-living environment. However, without accounting for appropriate bout duration when converting raw accelerometer data to SB parameters, an operational definition of sedentary time may not be congruent with what has been defined at the conceptual level (i.e., the time spent in prolonged SB). This may be an issue not only for Actigraph accelerometers but also for other accelerometers such as the posture classification device. A recent study (Harrington, Dowd, Bourke, & Donnelly, 2011) that utilized ActivPal accelerometer (PAL Technologies Ltd, Glasgow, UK) among adolescents defined a 15-second interval as a minimum duration of sitting time and the results also highlighted that a large number of sitting events occurred in short bout durations of <5-min. Although it would be challenging to determine the minimum duration of sedentary time which may negatively impact the physiological responses in the human body, the efforts to distinguish the time spent in *prolonged sedentary behavior* from accelerometer data should be made when the implication of the public health message is placed on *reducing prolonged sedentary time* and not on total sedentary time.

Are We Measuring Sedentary Breaks or the Number of Sedentary Bouts?

Sedentary break has emerged as one of the promising intervention components that may significantly decrease the risk of cardiovascular diseases (Healy et al., 2008; Owen et al., 2010). Dunstan et al. (2012) highlighted that even short bout of interruptions in sedentary time with light- or moderate-intensity walking significantly reduced the levels of postprandial glucose and insulin. Despite its potential for improving public health, little is known as to how to operationalize the breaks in sedentary time from accelerometry data that may provide the outputs congruent with what has been defined in the conceptual level. Particularly, the absolute number of transitions from sedentary to active phase has been extensively examined assuming that sedentary time is considered to be interrupted when transition occurs (Healy et al., 2008); however, the measurement properties of this approach has been questioned.

In this study, the accrued patterns of sedentary breaks using the algorithm used by Healy et al. (2008) showed that approximately 70% of sedentary breaks occurred at sedentary bouts of <5-min. (85% for <10-min), which is almost identical to what we found with respect to the number of sedentary bouts. Furthermore, the accrued sedentary breaks at 1-min bout duration are identical to the accrued sedentary time at 1-min bout duration. The underlying reason for this finding is that the current algorithm to extract sedentary breaks from raw accelerometer data is, indeed, an alternative expression to extract the number of sedentary bouts. In other words, counting the number of transition points from a sedentary to active phase would produce the same or slightly smaller quantity compared to the number of sedentary bouts. Only small differences would exist depending on the existence of sedentary time at the end of a continuous measurement period (e.g., sedentary time at the end of wear time or day would be considered as a sedentary bout but not counted for sedentary breaks). This notion could also be supported by the perfect linear relationships between sedentary time and breaks at each bout duration which clearly imply that sedentary breaks obtained by the current algorithm are an alternative parameter that quantifies the amount of sedentary time at each bout duration.

Meanwhile, the correlation coefficient between total sedentary time and total sedentary breaks was -.23, which may lead to the conclusion of a weak relationship between total sedentary time and breaks (Healy, Matthews, et al., 2011). However, this is because of the expansion of range in total sedentary time that significantly attenuates the relationship with total sedentary breaks. For example, 1-unit increases in total sedentary breaks may indicate an increase in total sedentary time by a minimum of one to thirty minutes or more depending on the sedentary bout durations where the breaks occurred. As shown in Table 4, the correlation coefficients between sedentary time and breaks get close to 1.0 as the range of sedentary time narrows for 1-unit increases in sedentary breaks.

While acknowledging the operational limitations of breaks in sedentary time, the transitions from a sedentary to active phase may include standing from a sitting position or walking a step which could also be considered as an indicator of physical activity. (Healy et al., 2008). However, as illustrated in Table 5, our results showed that significant and protective associations of sedentary breaks with health outcomes only hold true at bout durations of <5-min, while the deleterious associations were detected at the bout durations of ≥10-min. These findings are likely similar to the results we found with respect to sedentary time at each bout duration. Given that the sedentary breaks is an alternative score that represents the number of sedentary bouts as discussed above, the implications may be more related to the patterns of how sedentary time is accumulated rather than to physical activity which may matter for health (e.g., a higher number of sedentary events with long bout is deleteriously associated with health outcome). Therefore, sedentary breaks presented as absolute number of transitions from sedentary to active phase may not be considered as breaks in sedentary time or an indicator of physical activity, and caution is warranted when drawing conclusions about sedentary breaks in relation to health outcome.

Taken together all above mentioned evidence, it is plausible to say that sedentary breaks represented by absolute number of transitions from sedentary to active phase is an incomplete measure of the patterns of sedentary time that does not take account for the respective bout durations which may matter for health outcomes. Lyden et al. (2012) proposed break rate calculated by total number of breaks divided by total sedentary time as a feasible metric specifically for detecting intervention effects. However, given that the breaks is an alternative measure of number of sedentary bouts, it only represents the average number of sedentary bouts to accumulate one sedentary hour, which may be more relevant to the accumulation patterns of sedentary time rather than to breaks in sedentary time. On one side, Chastin and Granat (2010) proposed a standardized statistics, Gini index, which takes both the number of sedentary bouts and the respective bout durations into account; however, it may not be legitimate to consider Gini index as a measure of sedentary breaks, and more efforts to distinguish the breaks in sedentary time from the patterns of sedentary time accumulation should be made.

We believe that identifying the breaks or interruption in sedentary time in the observational study is a difficult task that cannot be comparable to examining the patterns of how sedentary time is accumulated. The noun break refers to *the interruption of continuity or uniformity* or *a pause in work or during an activity or event* (Oxford Dictionaries Online, 2013). This may imply that true breaks in sedentary time would possibly exist only within a continuous bout of SB pursuit. In other words, a strong assumption has to be made that sedentary is a fundamental behavior of the participants during the measurement period if the transition from a sedentary to active phase is to be considered as a sedentary break. For example, in the laboratory experimental study conducted by Dunstan et al. (2012), the participants were instructed to sit over 7 hours beginning with 2 hours to achieve steady state and then trail conditions (interruptions by 2-minute bouts of walking activities) were applied during the remaining 5 hours. The trial protocols were well-designed to fully reflect the conceptual definition of sedentary breaks (breaks or interruptions in sedentary time) because the participants were, again, forced to be sedentary during the measurement period. However, from an evolutionary perspective, humans are born to be active (Cordain, Gotshall, & Eaton, 1998), and it may not be legitimate to consider a simple transition from a sedentary to active as a "break in sedentary time" in a free-living environment in which we do not know whether the observed transitions have purposely occurred within the continuity of SB pursuits or just simply at the true end of SB pursuit. One possible approach to identify objectively measured sedentary breaks in free-living environments could be a combination with subjective measures (e.g., physical activity log/dairy) (Healy, Clark, et al., 2011), from which one can obtain the time period information where the fundamental behavior of the participants were expected or assumed to be sedentary (e.g., office hours).

There have been a few attempts to operationally define the *sedentary behavior bout* that may possibly include true breaks within the bout. Carson and Janssen (2011) defined a SB bout as a period of ≥30-minutes in which ≥80% of minutes are sedentary (i.e., <100 cpm) with no more than 5 consecutive minutes ≥100 cpm, from which the number of transitions from a sedentary to active phase was then extracted. Although there could be some practical issues such as restricting the break durations to <5 minutes, this could be one possible approach to overcome the limitation that may distinguish the operationalization of sedentary breaks from the patterns of sedentary time accumulation.

This study is not without limitations. First, the present study is data-driven research that relies on cross-sectional data that limits our ability to draw causal relationships of SB measures with health outcomes. Moreover, the implications of our findings are mainly limited to the practice of Actigraph accelerometer used in the NHANES 2003-2006 cycles, and caution is needed when interpreting the results for the study with different measurement protocols compared to the NHANES. Finally, the main focus of this study was limited to the data processing issues, particularly focusing on SB measures. There are several important issues in using accelerometer data for a large observational study, such as participants' compliance, non-wear time, or defining non-wear time which could not be addressed in the present study. The readers who are interested in these particular issues should refer to previous research (Matthews et al., 2012; Tudor-Locke, Camhi, & Troiano, 2012; Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005; Winkler et al., 2012) for an extensive understanding of those issues and to potentially address them in future research.

SB is purposefully engaged activities in different contexts that are predominated by prolonged sedentary time with low energy expenditure and possibly include sedentary breaks (Owen et al., 2010). However, the most commonly used algorithms to obtain SB parameters from accelerometer data may not perform well enough to fully reflect the conceptual definitions of respective parameters in free-living settings. The present study elucidated the necessity of determining the minimum duration of sedentary time that can potentially be considered as prolonged SB. Prior information on SB bouts would be required in order to identify true sedentary breaks that fully reflect the conceptual definition of sedentary breaks (i.e., interruptions in sedentary time). Future research should be aimed at developing a new algorithm/approach to discriminate SB bouts from the raw accelerometer data in order to improve the measurement properties of objectively measured SB in health outcome research.

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CHAPTER III

VALIDATION OF OBJECTIVE MONITORING DEVICES FOR THE ASSESSMENT OF SEDENTARY BHEAVIOR IN A FREE-LIVING ENVIRONMENT

Introduction

Sedentary behavior (SB), which is conceptually defined as any purposefully engaged activity that is predominated by prolonged sitting or a reclining posture with low energy expenditure (<1.5 METs) (Owen, Healy, Matthews, & Dunstan, 2010), has become a major health risk behavior in modern society. A rapidly growing evidence has demonstrated the negative impacts of sedentary behaviors on various health outcomes including, but not limited to cardiovascular risk factors, chronic disease related morbidity, and mortality (Bankoski et al., 2011; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Katzmarzyk & Lee, 2012; Koster et al., 2012; Wijndaele et al., 2011). Increased awareness of the importance of SB in public health has led to a huge demand for accurate assessment of SB in a free-living environment (Atkin et al., 2012; Marshall & Merchant, 2013).

Of the various types of methods to assess SB, objective methods using accelerometers have extensively been used in studies ranging from clinical trials to large-scale observational studies with greater reliability and validity compared to subjective methods (Atkin et al., 2012; Healy, Clark, et al., 2011). Several accelerometers have been developed by different manufacturers, and they can generally be classified into two broad categories (i.e., energy expenditure devices and postural devices) based on functional features as to how they capture the human movements (Granat, 2012).

Energy expenditure devices typically measure activities by examining the frequency and amplitude of accelerations generated by ambulatory movements to which they are attached. These raw accelerations are then analyzed with the manufacturer's software to provide output values in the form of activity counts, for user-defined time intervals (i.e., epochs). A number of thresholds of activity counts have been proposed for different intensity levels of physical activity across different manufacturer's accelerometers (Freedson, Melanson, & Sirard, 1998). For example, in one frequently used energy expenditure device, the Actigraph (ActiGraph LLC, Pensacola, FL) accelerometer, the threshold of activity counts for measuring SB is <100 counts per minute (cpm) (Matthews et al., 2008), which approximately corresponds to the energy cost of <1.5 METs. Postural classification devices like the activPal (Physical Activity Technologies, Glasgow, Scotland) use the inclinometer to detect the postural information and provide outputs within three classifications of activities (lying/sitting, standing, and walking), of which lying/sitting is commonly considered as SB (Harrington, Dowd, Bourke, & Donnelly, 2011; Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011).

Despite the promising aspects of using objective methods to better characterizing SB in a free-living setting, several measurement critiques have been raised for each type of monitoring device (Atkin et al., 2012; Granat, 2012; Marshall & Merchant, 2013). Most of the critiques, in general, were related to the difficulty of operationalizing SB congruent with what it has been defined at the conceptual level, particularly focusing on the components of energy expenditure (<1.5 METs) and posture (sitting). For instance, the researchers examining SB using energy classification devices may have to make an arbitrary assumption regarding body posture (i.e., sitting or lying) when estimated energy expenditures for the respective time intervals are less than the threshold of SB. Conversely, postural classification devices may fail to account for the energy expenditures when classifying lying/sitting to SB. However, previous studies that examined the validity of different types of accelerometer for assessment of SB in both laboratory and free-living settings generally concluded that the posture classification device (i.e., activPal) provides better estimates of time spent in SB with less bias and high accuracy while the performance of energy expenditure classification devices (e.g., Actigraph) using a fixed threshold may introduce significantly large random errors, potentially altering study outcomes (Kozey-Keadle et al., 2011; Lyden, Kozey-Keadle, Staudenmayer, & Freedson, 2012).

A continuous effort has been made to refine the methods in order to obtain accurate and precise estimates of SB from the energy expenditure classification devices, particularly focusing on posture classification. A new generation of Actigraph triaxial accelerometers (e.g., GT3X) is equipped with a built in inclinometer function that provides the information about participant’s posture (e.g., standing, lying, sitting) when the device is worn on the hip and perfectly vertical. Furthermore, advanced statistical techniques based on machine learning classification have been employed to develop the optimized algorithm to better classify the postures from the Actigraph accelerometer data. Lyden, Kozey-Keadle, Staudenmayer, and Freedson (2014) recently developed the method called *Sojourn*, which is a hybrid machine learning algorithm that combined the artificial neural network with hand-built decision tree analysis. The algorithm was validated among 7 healthy adults in a free-living environment and significantly improved the performance of Actigraph GT3X accelerometer for classifying SB compared with a direct observation. However, the validity of Actigraph inclinometer function for the assessment of SB is still questionable in a free-living setting (Carr & Mahar, 2012; Hänggi, Phillips, & Rowlands, 2012), and the performance of the sojourn method still needs to be further evaluated in different sample.

On the other hand, a recent study using an Actigraph accelerometer (Healy et al., 2008) reported that sedentary breaks, which is defined as interruptions in sedentary time, is a potential health indicator that is favorably associated with cardiovascular risk factors. A number of studies have begun to focus on sedentary breaks as a feasible strategy to improve an individual's health; however, a method to operationalize the sedentary breaks from accelerometer data was to count every transition point from sedentary to active phase, which has led the researchers to question whether it is breaks in sedentary time or the patterns of how sedentary time is accumulated which may matter for health (Colley et al., 2013). In our preliminary study using the National Health and Nutrition Examination Survey (NHANES) 2003-2006 accelerometry data, we found that an absolute number of sedentary breaks obtained using the current operational definition is an incomplete measure of the patterns how sedentary time is accumulated rather than the interruptions or breaks in sedentary time. We also proposed the necessity to develop the algorithm to identify the sedentary behavior bout (SB-bout) that is predominated by prolonged sedentary time and possibly includes true breaks within the bout.

SB measurement is a relatively new scientific area that still has a significant room for improvement. Specifically, establishing validity evidence of different accelerometers for assessment of SB and the refinement of a data processing algorithm to identify SB-bout would be necessary to improve the measurement practice of SB. Therefore, the purpose of this study is twofold: 1) to examine the validity of different types of accelerometers to assess SB in a free-living environment compared with a proxy for direct observation using Autographer (Oxford Metrics Group, plc., Oxford, UK) wearable camera; and 2) to develop a new algorithm that could potentially identify SB-bout, which may include true breaks or interruptions in sedentary time as congruent with what it has been conceptually defined.

Methods

Participants and Procedures

A convenience sample of 11 adults (male = 8) were recruited from a community in the mid-southern region of the US by word of mouth. The healthy adults between 20-60 years of age who do not have any physical disabilities or medical conditions that may hamper them to engage in normal daily activities were invited for this study. All invited participants had an initial meeting with the primary investigator, and the informed consent that was approved by the University Institutional Review Board was obtained. During this time, a careful explanation about the potential risk and privacy issues associated with using a wearable camera was provided. Demographic information including birthdate, gender, smoking status, and self-reported height (cm) and body weight (kg) were also obtained.

Upon completion of the informed consent form, the participants were asked to wear three accelerometers [Actigraph model GT3X, activPal, and SenseWear™ Armband (Model MF-SW; Body Media, Pittsburgh, PA, USA)] and an Autographer wearable camera on designated body location for the respective devices (waist over the right hips for Actigraph GT3X accelerometer; mid-anterior position on right thigh for activPal; triceps muscle on the left arm for SenseWear^{TM} Armband; and around the neck using a lanyard for Autographer). The measurement period was for up to approximately 6 hours in a single monitoring day until the Autographer automatically turned off due to the battery limits (average monitoring period = 366.54±21.47 minute). The participants were instructed to perform normal daily activities without any behavior modification, such as reducing SB or increasing physical activity during the measurement period.

Table 1

Demographic Characteristics of the Participants

	Total (*N* = 11)	Male (*n* = 8)	Female (*n* = 3)
Age (yr)	30.67 (7.24)	29.51 (12.59)	33.76 (7.92)
Height (cm)	173.27 (8.86)	178.25 (6.83)	160.00 (3.00)
Weight (kg)	76.70 (17.81)	83.11 (27.63)	59.59 (5.56)
BMI (kg/m^2)	25.36 (4.57)	26.15 (9.64)	23.26 (1.65)
Monitoring Period (min)	366.54 (21.47)	373.36 (20.49)	348.35 (12.34)

Note. Values are presented as *Mean* (*SD*)

Table 2

Characteristics of the Accelerometer Measures

Device	Output	SB Identification	Measure
Actigraph GT3X	Activity counts for 1-sec epoch	Sojourn method (vertical axis)	GT3X-Soj1x
		Sojourn method (three axis)	GT3X-Soj3x
		Inclinometer	GT3X-Incli-1s
	Activity counts for 10-sec epoch	<8 counts	GT3X-<8cnts/10s
		Inclinometer	GT3X-Incli-10s
	Activity counts for 60-sec epoch	<50 cpm	GT3X-<50cpm
		<100 cpm	GT3X-<100cpm
		<150 cpm	GT3X-<150cpm
		Inclinometer	GT3X-Incli-60s
activPal 3C	Activity Events (time with seconds)	Lying/Sitting	activPal
SenseWear™ Armband (Model MF-SW)	METs /min	< 1.5 METs	Armband
Autographer (Criterion)	Images (time with seconds)	Standardized Coding Protocol	Autographer

Note. All measures were synchronized to a 1-second data; SB = sedentary behavior, cpm = counts per minute

Accelerometer Measures and SB Identification

Actigraph. The Actigraph GT3X accelerometer, which is a light and small (27g; 3.8 cm x 3.7 cm x 1.8 cm) triaxial accelerometer capable of recording accelerations in three axes (vertical, anterior posterior, and medial-lateral), was used for this study. The GT3X measures accelerations at ranging from 30 Hz sampling rate in response to the magnitude from ±3g, which is, in turn, integrated over a user-defined epoch length as activity counts. For this study, Actigraph GT3X device was programmed to record accelerations in 1-second epochs with low-frequency extension in order to increase the sensitivity to capture low-intensity movements including SB. The device was attached on an adjustable elastic belt, and the participants were asked to wear the accelerometers on the waist over the right hip (perfectly vertical) in order to ensure the use of inbuilt inclinometer function of the GT3X for posture classification (lying, sitting, standing, and off).

Actilife software version 5.10.0 was used to initialize the device and to download the time-stamped accelerometer data by 1-second. Because there is no empirically proposed activity count threshold for SB in 1-second epoch, the data were collapsed into 60- and 10-second epoch lengths to apply the thresholds of <50 cpm, <100 cpm, and <150cpm for 60-second and <8 counts per 10 second for 10-second data (Crouter, Dellavalle, Haas, Frongillo, & Bassett, 2013; Kozey-Keadle et al., 2011; Lyden et al., 2012; Matthews et al., 2008). A time interval with vertical activity counts less than the thresholds was considered sedentary time for the respective thresholds. The inclinometer outputs from 1-second and collapsed 60- and 10-seconds data were also obtained, and the time intervals classified as lying or sitting were considered sedentary time for the respective data.

Two different versions of the sojourn method were applied to identify SB from the second-by-second GT3X accelerometer data. The first version (Soj-1x) employs the hand-built decision tree approach to identify SB using activity counts from vertical axis only. Briefly, the decision tree classifies time intervals for two types of SB (i.e., ‘sitting or lying fairly still’ and ‘sitting with minor movement’) based on the characteristics of two classifier parameters (i.e., percentages and/or durations of nonzero activity counts) for the respective time intervals. The second version (Soj-3x) uses the second-by-second activity counts from three axes (vertical, anterior-posterior, and medial-lateral). The similar classifier parameters (i.e., percentages and durations of nonzero activity counts from the vertical axis) but with different criterion are used in combination with an artificial neural network to identify the time intervals that may be featured with “sitting or lying fairly still” or “sitting with minor movement”. The detailed description of sojourn method can be found from Lyden et al. (2014), and the entire sojourn algorithm based on an open source *R*-language is available at www.math.umass.edu/~jstauden/SojournCode.zip.

ActivPal. The activPal^{3TM} is a light and small (15g; 3.5 cm x 5.3 cm x 0.7 cm) triaxial accelerometer, worn on the mid-anterior position of the right thigh. The device measures accelerations of the thigh at a sampling frequency of 20 Hz, which is used to produce the signals related to thigh inclination. Using the proprietary algorithm in the manufacturer-provided software, the final output for body postures (lying/sitting, standing, and walking) was provided. The activPal3 software version 7.1.18 was used to initialize the device and to download accelerometer data. The event data that provides the exact observed time with seconds when posture was changed was expanded to 1-second data for later analyses. A time period in which the posture was classified as lying/sitting was considered sedentary time.

Sensewear^{TM} Armband. The SenseWear^{TM} Armband (Model MF-SW) is a light and small (45g; 5.5 cm x 6.2 cm x 1.3 cm) multi-sensor body monitoring device which include a triaxial accelerometer, skin temperature sensor, galvanic skin response sensor and thermometers for measuring heart flux. The device was configured with self-reported height (cm), body weight (kg), birth date, gender, smoking status, and handedness per the manufacturer's instructions.The device was worn over the triceps muscle and the Sensewear software version 7.0 with propriety algorithm version 2.2.3 was used to estimate energy expenditure (e.g., METs) for 60-second epochs. A time interval with MET <1.5 was considered sedentary time and the data was expanded to 1-second data for later analyses.

Criterion Measure: Autographer. The Autographer is a new generation of SenseCam which was the first wearable camera used in lifelogging research (Doherty et al., 2011; Kerr et al., 2013). The device is light and small (58g; 3.74 cm x 9.55 cm x 2.29 cm), and incorporates five sensors (triaxial accelerometer, magnetometer, ambient temperature, light level, and passive infrared) to determine the best moment to automatically capture the images without any user intervention. The device was set to capture the images at high rate (approximately 10 images per minute), and the participants were instructed to wear the Autographer around the neck using a lanyard.

Autographer's custom-built software was used to upload, store, and review the time-stamped images taken during the measurement period. A standardized coding protocol developed from Kerr et al. (2013) for the SenseCam image data was modified for this study. Specifically, a restriction relative to the number of consecutive images (approximately for 2 minutes) to define the sedentary "event" in the original coding protocol was relaxed in order to reflect all SB regardless of the durations. A series of visual cues including the limbs positions (e.g., hands on or legs underneath a table), camera angles (e.g., lower than the persons who were standing), and the associated environments (e.g., not involved in the exercise-related environments such as bicycling, static stretching, yoga, or weight lifting) of each image were simultaneously considered to identify SB that are congruent with what it has been defined at the conceptual level. Three observers who have sufficient training in the area of physical activity at the graduate level independently coded the image data for all participants. The discrepancies across observers were resolved by comprehensive discussion until they reach a consensus. The second-by-second time intervals of the continuous images that were coded SB were obtained.

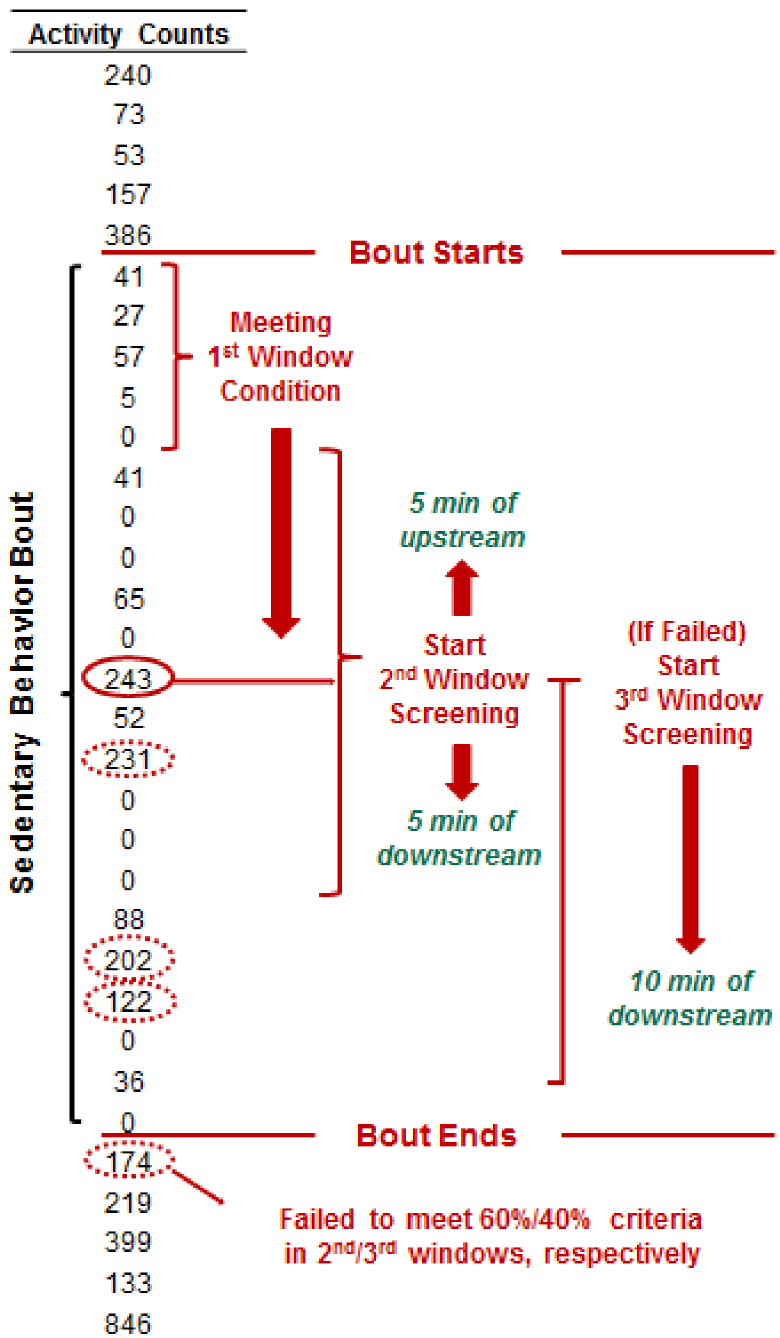

Figure 1

Illustration of new algorithm searching process to identify the SB- bout from Actigraph accelerometer data (1-min epoch) using the threshold of <100 cpm

Development of a New Algorithm

The new algorithm to identify SB-bout was developed using SAS v9.3 (SAS Institute Inc, Cary, NC) and includes three sequential screening windows with user modifiable searching parameters.

1) 1st window – Search for the beginning of SB-bout if 5 consecutive minutes (300 consecutive seconds) identified as SB are observed.
2) 2nd window – Start from the time point that is not sedentary after meeting the condition of 1st window. Examine 5 consecutive minutes (300 consecutive seconds) of upstream and downstream from the time point that is not sedentary. If 60% of 2nd window is sedentary then move onto next minute that is not sedentary and repeat 2nd window.
3) 3rd window – If the condition of 2nd window is not met, examine 10 minutes (600 consecutive seconds) of downstream from the time point that failed to meet the condition of 2nd window. If 40% of the 3rd window is sedentary then move onto next minute that is not sedentary and repeat 2nd window. If the data do not meet the condition of 3rd window, stop searching and record the time point where the 2nd window starts as the end of SB-bout.

The new algorithm was applied to all SB measures including the criterion, and three outcome variables were obtained for each SB measure.

1) SB-bout – The time interval between the time point that meet the condition of 1st window and the time point that does not meet the conditions of 3rd window.
2) Sedentary time – Total accumulated sedentary time within SB-bout.

3) Breaks in sedentary time – Transition from sedentary to active phase within SB-bout.

Data Analysis

All accelerometer data managements and statistical analyses were performed using SAS version 9.3. A graphical representation of the results was performed using *R*-language. Descriptive statistics [Mean and 95% confidence interval (CI)] of SB parameters including total sedentary time, the number of observed SB (i.e., events), and the average duration of SB were obtained for each accelerometer measure.

To address aim 1, which is to examine the validity of different types of accelerometer for assessment of SB, two approaches with different levels of focus (i.e., an aggregated level and a second-by-second level) were employed. First, average differences in total sedentary time between the estimates from the accelerometer and the criterion was calculated to quantify the prediction errors of total sedentary time estimated from each accelerometer. Mean differences were presented by two statistical indices, mean absolute percentage error (MAPE, %) and percentage (%) of bias, in order to provide overall magnitude of the errors due to the bias and the direction of the bias (e.g., under- or over-estimation), respectively. A 95% CI associated with the % of bias was also considered as a proxy indicator for precision of the estimates. Second, the second-by-second accelerometer data were compared with the time-matched, second-by-second criterion data with sedentary time intervals identified for each participant. The proportions of the sedentary time intervals that are correctly classified (e.g., true positive) and misclassified (e.g., false positive) as sedentary time intervals compared to the criterion data were presented as sensitivity (%) and 1-speicificity (%). Youden's index, which is the difference between the sensitivity and 1-specificity, was calculated as a relative approximation to the overall performance of each accelerometer to identify true sedentary time. Mean sensitivity, 1-specificity, and Youden's index across all participants were calculated along with the associated 95% CIs. Phi coefficients were additionally obtained for each measure as an index of association with the criterion.

Additional datasets that include sedentary time intervals with different bout conditions of ≥300-sec (5-min), ≥600-sec (10-min), ≥900-sec (15-min), and ≥1200-sec (20-min) were created for all SB measures including the criterion in order to examine the performance of each accelerometer to identify the structured SB given bout conditions. The changes in MAPE, percentage of bias, sensitivity, and 1-specificity for each accelerometer were calculated across different bout conditions.

To examine the validity of the new algorithm to determine SB-bout from the accelerometer measures, the new algorithm was first applied to all measures, including the criterion. Descriptive statistics (Mean and 95% CI) were calculated for three SB parameters including total estimated time, the number of observed events, and average durations across three outcome variables (SB-bout, sedentary time within a bout, and sedentary breaks within a bout). Statistical approaches to address aim 2 were identical to those employed to address aim 1. The mean differences of total estimated time across three outcome variables between the accelerometer measures and the criterion were expressed as MAPE (%) and the % of bias. Sensitivity and 1-specificity were obtained by comparing the second-by-second time intervals for SB-bout between the accelerometer measures and the criterion for each participant and presented as mean and 95% CI.

Results

Validity of Accelerometer Measures to Identify SB

Table 3 presents the descriptive statistics of SB parameters across the measures estimated from different types of accelerometers. The observed total sedentary time from the criterion indicated that the participants generally spent a large amount (>70%) of their monitoring period with SB. The estimated sedentary times from accelerometer measures were not statistically different from the criterion (Mean = 246.57 min; 95% CI = 181.63, 313.51) which was evidenced by the overlapped 95% CIs; however, the number of SB and the average duration of SB estimated from each accelerometer measure were statistically different from the criterion (Mean = 13.27; 95% CI = 9.44, 17.11; and Mean = 20.66 min; 95% CI = 13.77, 27.54, respectively). Significantly larger numbers of SB were identified across all measures compared with the criterion with the exceptions of GT3X-Soj3x (Mean = 13.73; 95% CI = 10.24, 17.22), GT3X-Incli-60s (Mean = 22.45; 95% CI = 14.92, 29.99), activPal (Mean = 18.18; 95% CI = 12.73, 23.64), and Armband (Mean = 12.63; 95% CI = 7.57, 17.68). Significantly smaller average duration of SB was estimated compared with the criterion across all measures with the exceptions of GT3X-Soj3x (Mean = 18.67; 95% CI = 12.7, 24.64), GT3X-<100cpm (Mean = 10.43; 95% CI = 6.48, 14.38), GT3X-<150cpm (Mean = 12.54; 95% CI = 7.49, 67.58), activPal (Mean = 15.65; 95% CI = 8.92, 22.37), and Armband (Mean = 13.46; 95% CI = 7.48, 19.44).

Table 3

Descriptive Statistics of SB Parameters Across Accelerometer Measures

	Autographer	GT3X 1-sec epoch			GT3X 10-sec epoch		GT3X 60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-<8cnts/10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Total Sedentary Time (min)	247.57 (181.63, 313.51)	236.28 (172.89, 299.67)	224.96 (168.67, 281.26)	191.39 (138.54, 244.25)	262.77 (217.57, 307.96)	190.43 (137.78, 243.09)	233.23 (182.23, 284.23)	254.69 (207.64, 301.74)	264.98 (219.12, 310.83)	189.33 (135.79, 242.87)	236.85 (174.10, 299.61)	202.64 (146.36, 258.93)
Number of SB	13.27 (9.44, 17.11)	13.73 (10.24, 17.22)	23.82 (18.85, 28.79)	55.09 (35.60, 74.58)	137.00 (109.11, 164.89)	53.00 (34.53, 71.67)	32.00 (24.77, 39.23)	27.82 (22.11, 33.53)	24.91 (19.03, 30.79)	22.45 (14.92, 29.99)	18.18 (12.73, 23.64)	13.45 (9.75, 17.16)
Mean Durations (min)	20.66 (13.77, 27.54)	18.67 (12.70, 24.64)	10.07 (6.63, 13.51)	4.29 (2.76, 5.81)	2.16 (1.39, 2.93)	4.38 (2.86, 5.91)	8.52 (4.96, 12.08)	10.43 (6.48, 14.38)	12.54 (7.49, 67.58)	9.75 (7.00, 12.49)	15.65 (8.92, 22.37)	13.46 (7.48, 19.44)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Accuracy and precision of total sedentary time estimated from each accelerometer measure compared with the criterion are presented in Table 4. The results at the aggregated level indicated that activPal showed the most accurate estimate of total sedentary time with MAPE of 4.11 % (95% CI = 0.00, 8.42) and % of bias of -3.52% (95% CI = -8.08, 1.36), followed by GT3X-Soj3x with MAPE of 7.26% (95% CI = 2.28, 12.24) and % of bias of -2.81% (95% CI = -9.67, 4.05). The GT3X inclinometer-based measures and Armband significant underestimated the total sedentary time from the criterion which was evidenced by the negative limits of 95% CIs for GT3X-Incli-1s (% of bias = -18.94; 95% CI = -32.15, -5.49), GT3X-Incli-10s (% of bias = -19.32; 95% CI = -33.15, -5.49), GT3X-Incli-60s (% of bias = -19.91; 95% CI = -34.12, -5.70), and Armband (% of bias = -16.37; 95% CI = -27.81, -4.92).

At the second-by-second level, activPal demonstrated the best performance for the classification of sedentary time intervals compared with the criterion, which was evidenced by the highest phi-coefficient (.89; 95% CI = .81, .97), sensitivity (95.01%; 95% CI = 90.54, 99.47), and smallest 1-specificity (2.52; 95% CI = 1.54, 3.50). Youden's index was largest for activPal (Youden's index = 92.48; 95% CI = 87.26, 97.70) with non-overlapped 95% CI with other accelerometer measures, followed by GT3X-Soj3x with Youden's index of 74.74 (95% CI = 68.05, 81.42).

Table 4

Validity of Accelerometer Measures for the Assessment of SB

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	7.26 (2.28, 12.24)	12.49 (5.60, 19.39)	21.67 (10.05, 33.29)	24.69 (0.00, 55.72)	21.93 (10.18, 33.67)	18.69 (1.73, 35.66)	22.73 (0.00, 53.68)	25.15 (0.00, 61.48)	22.52 (10.39, 34.65)	4.11 (0.00, 8.42)	17.67 (7.23, 28.11)
% of bias	-2.81 (-9.67, 4.05)	-5.29 (-15.83, 5.25)	-18.94 (-32.73, -5.15)	21.14 (-11.17, 53.45)	-19.32 (-33.15, -5.49)	3.00 (-18.38, 24.38)	17.05 (-15.66, 49.77)	23.19 (-13.78, 60.16)	-19.91 (-34.12, -5.70)	-3.52 (-8.08, 1.36)	-16.37 (-27.81, -4.92)
Second-by-second level											
Phi-coefficient	0.72 (0.64, 0.79)	0.60 (0.48, 0.72)	0.54 (0.36, 0.72)	0.54 (0.42, 0.67)	0.54 (0.36, 0.72)	0.57 (0.46, 0.69)	0.60 (0.48, 0.71)	0.61 (0.48, 0.74)	0.54 (0.36, 0.73)	0.89 (0.81, 0.97)	0.52 (0.40, 0.64)
Sensitivity	89.90 (85.08, 94.72)	81.40 (72.18, 90.63)	74.35 (61.75, 86.95)	90.05 (86.43, 93.68)	74.19 (61.53, 86.84)	83.69 (78.12, 89.25)	90.50 (87.52, 93.48)	93.03 (90.83, 95.23)	73.97 (61.01, 86.92)	95.01 (90.54, 99.47)	74.17 (62.52, 85.82)
1-Specificity	15.16 (8.15, 22.17)	15.44 (7.83, 23.06)	14.19 (5.15, 23.24)	35.07 (24.22, 45.92)	13.70 (4.90, 22.49)	21.26 (12.07, 30.45)	28.70 (16.59, 40.8)	32.20 (18.68, 45.71)	13.50 (4.46, 22.53)	2.52 (1.54, 3.50)	16.75 (9.50, 23.99)
Youden's Index	74.74 (68.05, 81.42)	65.96 (53.29, 78.63)	60.16 (43.08, 77.24)	54.98 (42.75, 67.21)	60.49 (43.57, 77.41)	62.42 (51.08, 73.77)	61.80 (49.99, 73.62)	60.83 (47.30, 74.36)	60.47 (43.45, 77.49)	92.48 (87.26, 97.70)	57.42 (45.51, 69.33)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Validity of Accelerometers Measures to Identify Structured SB

Descriptive statistics of SB parameters across accelerometer measures after accounting for bout conditions of ≥300-sec, ≥600-sec, ≥900-sec, and ≥1200-sec are provided in the Supplemental Tables 1 through 4, respectively (See Appendix C). The validity of accelerometer measures for identifying time intervals with structured SB at a given bout of ≥300-sec, ≥600-sec, ≥900-sec, and ≥1200-sec are provided in the Supplemental Tables 5 through 8, respectively (See Appendix C).

Figure 1 depicts the changes in % of bias for total sedentary time estimated from each accelerometer compared with the criterion across the bout conditions. On average, most of GT3X-based SB measures (GT3X-Soj1x, GT3X-Incli-1s, GT3X-8cnts<10s, GT3X-Incli-10s, GT3X<50cpm, and GT3X-Incli-60s) significantly underestimated actual total sedentary time compared with the criterion after accounting for bout conditions. GT3X-Soj3x showed the most accurate and stable estimates of total sedentary time across the bout conditions, which was evidenced by the narrow range of 95% CIs that include absolute zero at the given bout conditions.

Figure 2 depicts the changes in sensitivity, 1-specificity, and Youden’s index across the bout conditions. There was a reduction in 1- specificity as increased restrictions on the bout condition across all SB measures. Similarly, the increase in bout conditions resulted in decreases in specificity across all accelerometer measures, with the exceptions of GT3X-Soj3x and Armband which demonstrated relatively stable levels of sensitivity across the bout conditions.

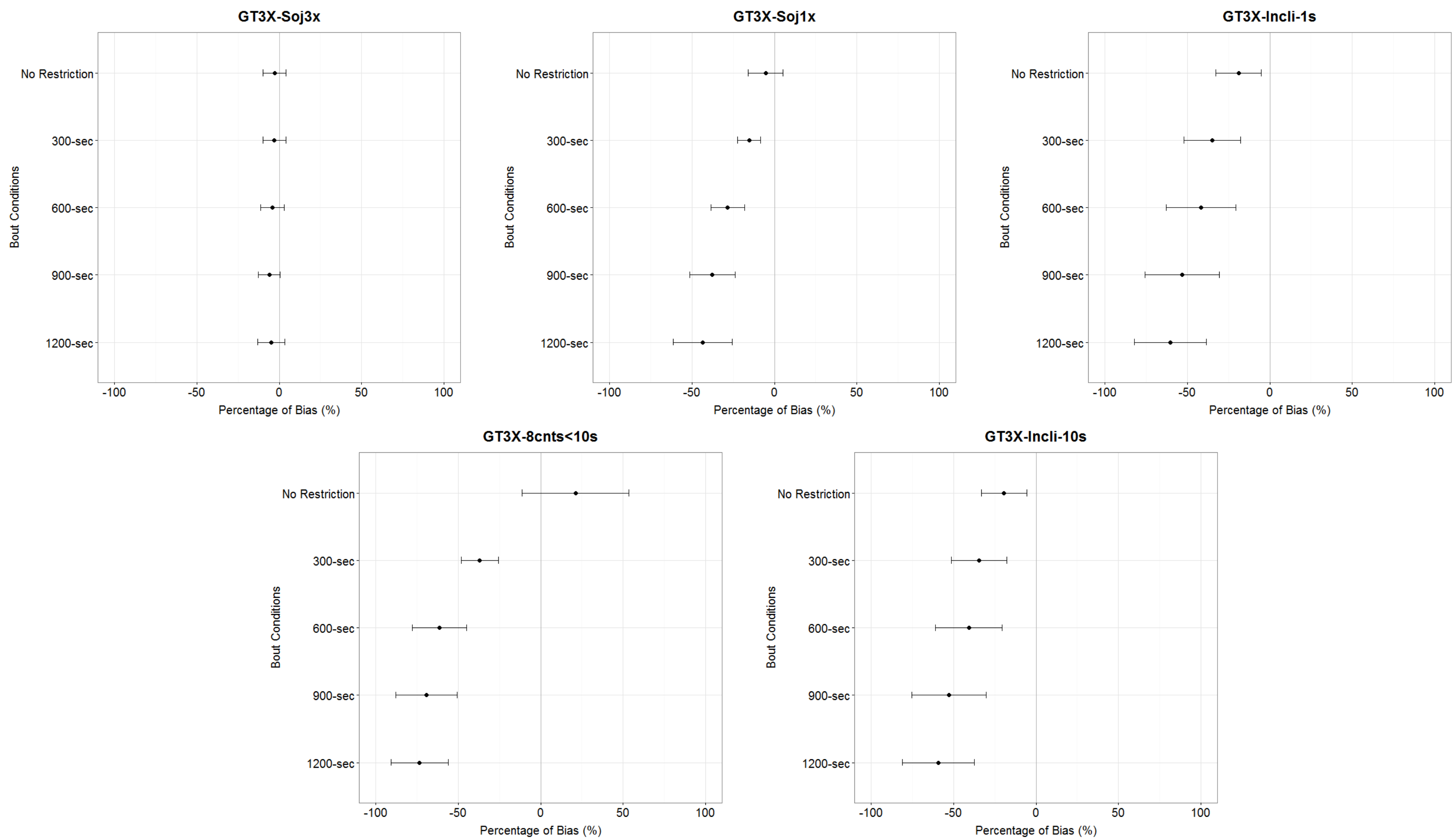

Figure 2
Illustrations of changes in % of bias (95% CI) on the estiamted total sedentary time from accelerometer meaures compared to the criterion across the bout conditions

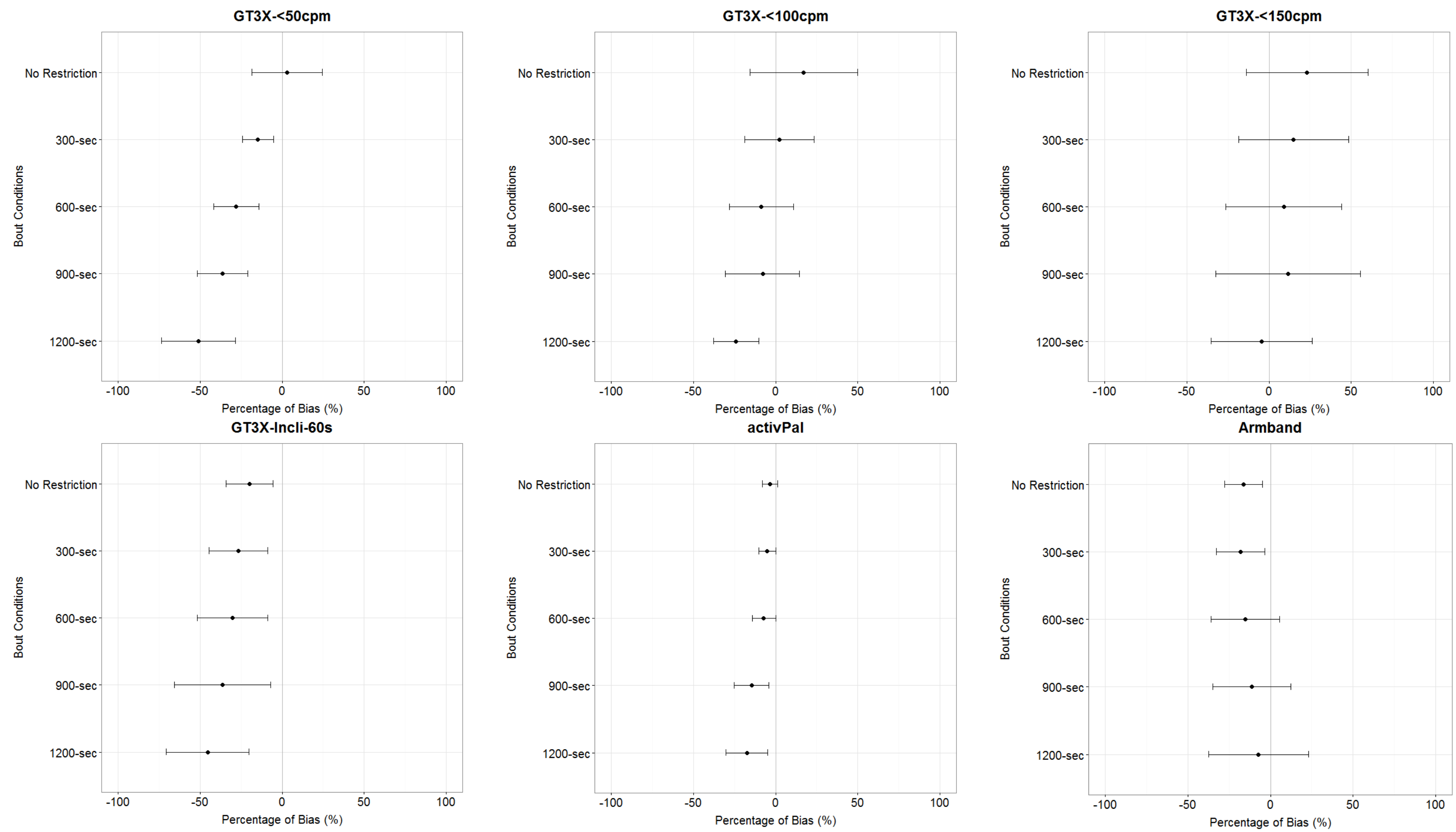

Figure 2 (Cont)
Illustrations of changes in % of bias (95% CI) on the estiamted total sedentary time from accelerometer meaures compared to the criterion across the bout conditions

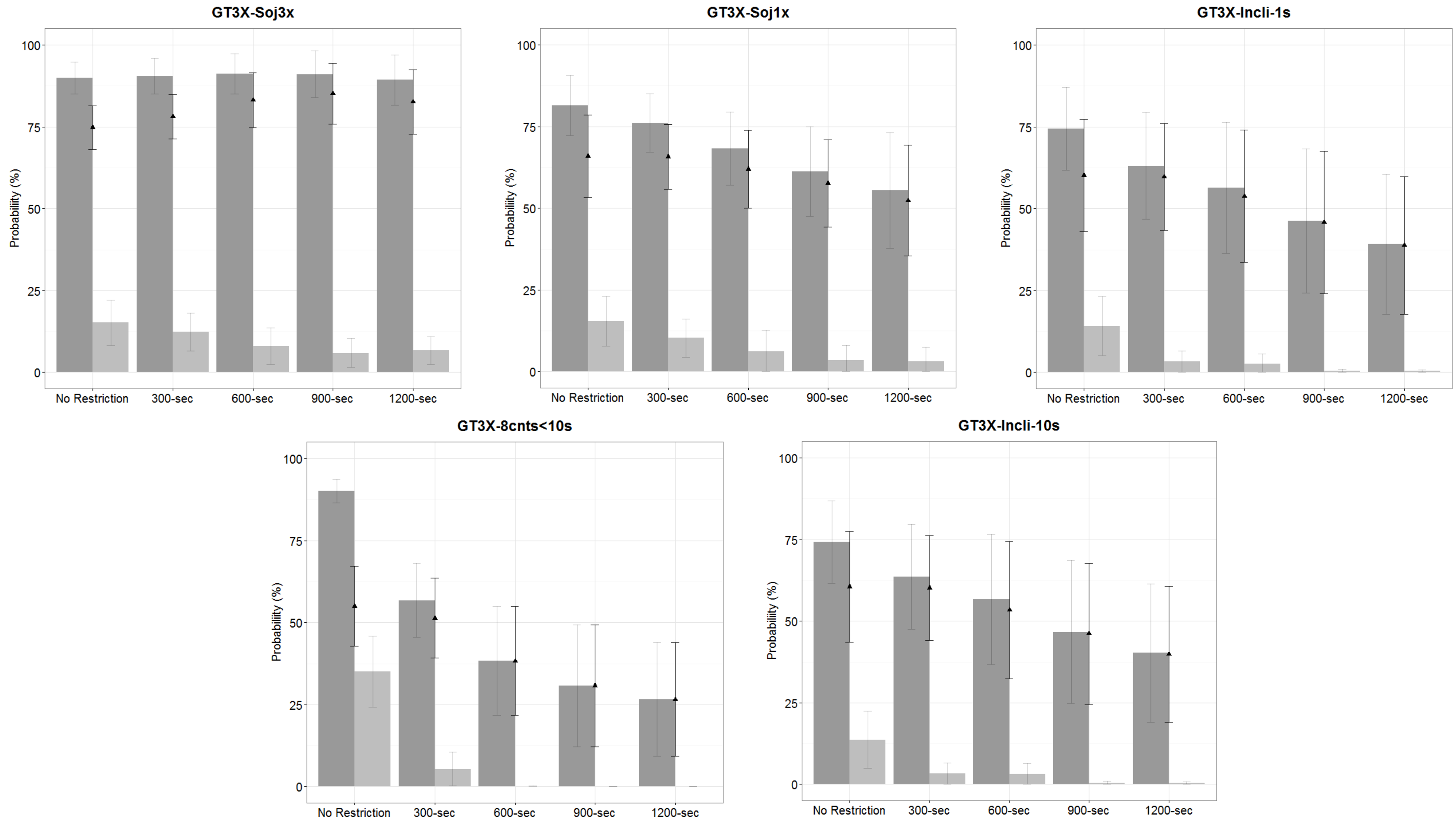

Figure 3

Illustrations of changes in sensitivity (dark grey on left), 1-specificity (light grey on right), and Youden's Index (black triangle in the middle) for accelerometer measures compared to the criterion across the bout conditions

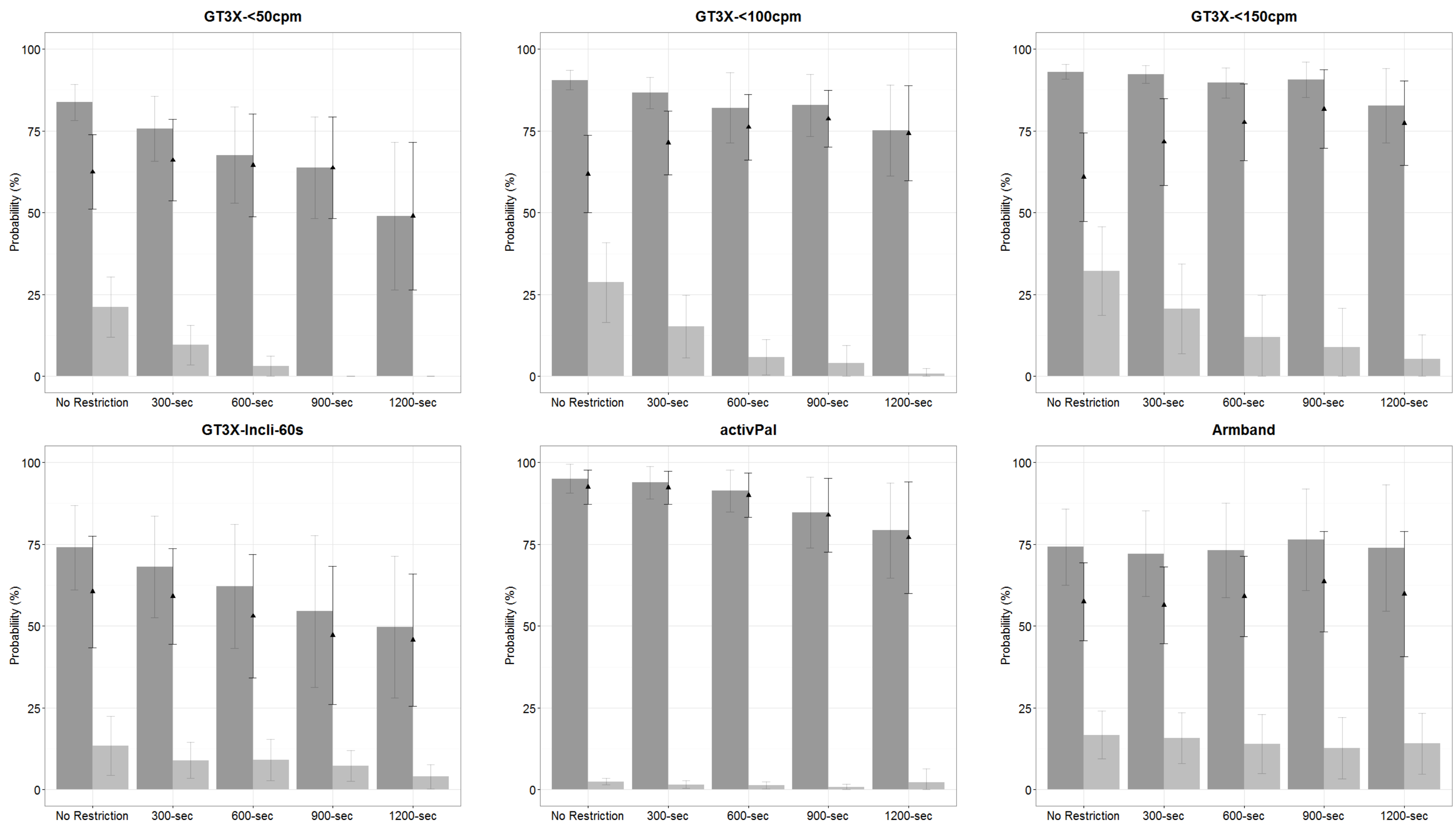

Figure 3 (Cont)

Illustrations of changes in sensitivity (dark grey on left), 1-specificity (light grey on right), and Youden's Index (black triangle in the middle) for accelerometer measures compared to the criterion across the bout conditions

Validity of Accelerometer Measures to Identify SB-bout using a New Algorithm

Three outcome variables including SB-bout, sedentary time and breaks within the bout were estimated from all accelerometer measures including the criterion using the new algorithm. Descriptive statistics of SB parameters for the respective outcome variables are presented in Table 5.

On average, the estimated total time for SB-bout from the criterion was 249.83 min (95% CI = 181.89, 317.90), which was accumulated by an average of 4.27 SB-bouts (95% CI = 3.37, 5.18). The estimated total sedentary time and total number of sedentary breaks within the bout resulting from new algorithm in the criterion were 240.99 min (95% CI = 175.93, 306.06) and 5.73 (95% CI = 3.21, 8.24), respectively.

All accelerometer measures generated similar mean estimates for the outcome variables of SB-bout compared with the criterion, which was evidenced by overlapped 95% CIs with the criterion. The estimated total sedentary time within SB-bout was not significantly different from the criterion; however, the number of sedentary events within SB-bouts significantly differed from the criterion (Mean = 10.00; 95% CI = 7.52, 12.48) in GT3X-8cnts<10s (Mean = 84.36; 95% CI = 58.53, 110.20), GT3X-<100cpm (Mean = 18.82; 95% CI = 14.58, 23.05), and GT3X-<150cpm (Mean = 17.27; 95% CI = 13.04, 21.50). Pertaining to the number of sedentary breaks within SB-bout, thresholds-based GT3X measures including GT3X-8cnt<10s (Mean = 81.82; 95% CI = 55.64, 107.99), GT3X-<50cpm (Mean = 15.18; 95% CI = 8.31, 22.05), GT3X-<100cpm (Mean = 15.09; 95% CI = 10.75, 19.43), and GT3X-<150cpm (Mean = 13.36; 95% CI = 8.92, 17.80) produced significantly different mean estimates from the criterion.

Table 5

Descriptive Statistics for Three Outcome Variables of SB-bout

	Autographer	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
SB-bouts												
Total Time for SB-bout (min)	249.89 (181.89, 317.90)	240.27 (172.99, 307.56)	228.35 (167.45, 289.24)	173.61 (113.34, 233.88)	258.70 (120.13, 316.21)	172.11 (112.48, 231.74)	236.82 (170.09, 303.55)	263.82 (208.22, 319.42)	274.19 (220.96, 327.41)	179.46 (119.75, 239.16)	241.79 (177.14, 306.44)	199.47 (138.89, 260.05)
Number of SB-bout	4.27 (3.37, 5.18)	4.91 (3.42, 6.39)	4.64 (3.72, 5.55)	4.82 (4.03, 5.60)	2.55 (1.73, 3.36)	4.64 (3.88, 5.39)	4.27 (3.74, 4.80)	3.73 (2.87, 4.58)	3.91 (2.77, 5.05)	4.73 (3.93, 5.53)	4.73 (3.68, 5.77)	5.27 (4.47, 6.07)
Mean Durations (min)	64.84 (39.71, 89.98)	64.30 (28.46, 100.13)	52.25 (35.26, 69.24)	36.51 (23.60, 49.41)	129.78 (72.53, 187.02)	37.53 (24.60, 50.46)	54.45 (40.15, 68.74)	78.11 (57.07, 99.14)	82.96 (56.97, 108.94)	38.79 (26.04, 51.54)	56.91 (34.00, 79.83)	37.93 (25.56, 50.29)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Table 5 (*Cont*)

Descriptive Statistics for Three Outcome Variables of SB-bout

	Autographer	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Sedentary Time within SB-bout												
Total Sedentary Time (min)	240.99 (175.93, 306.06)	229.89 (166.15, 293.63)	212.89 (154.97, 270.81)	161.76 (107.05, 216.48)	229.08 (175.02, 283.14)	159.96 (105.94, 213.97)	211.10 (150.76, 271.43)	237.55 (185.34, 289.76)	251.28 (201.48, 301.08)	167.46 (112.79, 222.12)	229.58 (167.50, 291.67)	192.38 (134.57, 250.19)
Number of Sedentary Events	10.00 (7.52, 12.48)	10.09 (7.08, 13.10)	17.55 (13.44, 21.65)	19.45 (10.67, 28.24)	84.36 (58.53, 110.20)	18.73 (10.02, 27.43)	19.45 (12.26, 26.65)	18.82 (14.58, 23.05)	17.27 (13.04, 21.50)	11.18 (7.22, 15.14)	12.55 (9.17, 15.92)	8.73 (5.88, 11.58)
Mean Durations (min)	25.13 (18.17, 32.10)	23.49 (17.85, 29.13)	12.14 (9.41, 14.87)	9.80 (6.90, 12.69)	3.20 (2.07, 4.33)	10.11 (7.17, 13.04)	12.26 (8.41, 16.11)	13.65 (9.72, 17.58)	16.01 (11.23, 20.79)	15.96 (12.55, 19.36)	19.70 (13.81, 25.59)	24.05 (15.92, 32.19)

Note. Values are presented as *Mean* (*95% CI*)

Table 5 (*Cont*)

Descriptive Statistics for Three Outcome Variables of SB-bout

	Autographer	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Sedentary Breaks within SB-bout												
Total Break Time (min)	8.90 (4.87, 12.93)	10.38 (3.76, 17.01)	15.46 (10.97, 19.95)	11.85 (5.24, 18.46)	29.62 (20.12, 39.12)	12.15 (5.47, 18.83)	25.73 (14.51, 36.94)	26.27 (19.64, 32.90)	22.91 (15.83, 29.99)	12.00 (6.04, 17.96)	12.21 (8.13, 16.28)	7.09 (2.37, 11.81)
Number of Sedentary Breaks	5.73 (3.21, 8.24)	5.18 (1.84, 8.52)	12.91 (8.76, 17.06)	14.64 (5.86, 23.42)	81.82 (55.64, 107.99)	14.09 (5.40, 22.79)	15.18 (8.31, 22.05)	15.09 (10.75, 19.43)	13.36 (8.92, 17.80)	6.45 (2.67, 10.24)	7.82 (4.71, 10.92)	3.45 (0.86, 6.05)
Mean Durations (min)	1.63 (1.27, 1.99)	2.02 (1.61, 2.44)	1.25 (1.06, 1.43)	0.86 (0.60, 1.11)	0.37 (0.31, 0.44)	0.93 (0.67, 1.19)	1.76 (1.58, 1.94)	1.79 (1.56, 2.03)	1.77 (1.51, 2.02)	2.02 (1.73, 2.31)	1.69 (1.40, 1.98)	2.54 (1.46, 3.62)

Note. Values are presented as *Mean* (*95% CI*)

The results of validity examination of accelerometer measures using the new algorithm are presented in Table 6 through 8 for the following outcome variables, SB-bout, sedentary time, and sedentary breaks within a SB-bout.

In general, the inclinometer-based GT3X and Armband measures significantly underestimated the total time for SB-bout [% of bias = -27.73 (95% CI = -44.91, -10.55) for GT3X-Incli-1s, % of bias = -28.19 (95% CI = -45.38, -11.01) for GT3X-Incli-10s, and % of bias = -24.66 (95% CI = -42.25, -7.06) for GT3X-Incli-60s, and % of bias = -19.26 (95% CI = -31.96, -6.56) for Armband] compared with the criterion. The best performance, with the lowest MAPE of 4.86 (95% CI = 0.45, 9.27) and 1-specificity of 2.06 (95% CI = 0.00, 4.26), and highest sensitivity of 96.27 (95% CI = 91.62, 100.00) and phi-correlation coefficient of .91 (95% CI = .82, 1.00) was observed in activPal measure.

The activPal identified sedentary time within SB-bout the best compared to the criterion, with the highest Youden's index of 92.56 (95% CI = 87.56, 97.56), followed by GT3X-Soj3x with Youden's index of 76.90 (95% CI = 70.01, 83.78). ActivPal also showed highest Youden's index of 86.05 (95% CI = 75.52, 96.58), followed by two threshold-based GT3X-measures including GT3X-<150cpm (Youden's index = 72.78; 95% CI = 58.67, 86.89), and GT3X-<100cpm (Youden's index = 71.49 (95% CI = 55.99, 86.98) when assessing sedentary breaks within SB-bouts.

Table 6

Validity of Accelerometer Measures for Assessment of SB-bout Using a New Algorithm

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	9.28 (3.20, 15.36)	11.42 (3.96, 18.88)	27.85 (10.77, 44.93)	28.00 (0.00, 64.02)	28.26 (11.13, 45.39)	17.62 (4.81, 30.43)	28.42 (0.00, 63.15)	28.68 (0.00, 64.76)	27.91 (12.92, 42.9)	4.86 (0.45, 9.27)	21.11 (9.96, 32.26)
% of bias	-2.14 (-10.94, 6.66)	-5.86 (-16.03, 4.31)	-27.73 (-44.91, -10.55)	17.56 (-21.60, 56.72)	-28.19 (-45.38, -11.01)	-2.18 (-19.95, 15.59)	20.17 (-17.32, 57.65)	25.37 (-11.92, 62.66)	-24.66 (-42.25, -7.06)	-2.29 (-7.64, 3.05)	-19.26 (-31.96, -6.56)
Second-by-second level											
Phi-coefficient	0.73 (0.64, 0.81)	0.63 (0.50, 0.76)	0.55 (0.36, 0.74)	0.52 (0.33, 0.70)	0.55 (0.36, 0.73)	0.64 (0.52, 0.76)	0.59 (0.42, 0.76)	0.62 (0.45, 0.79)	0.53 (0.35, 0.71)	0.91 (0.82, 1.00)	0.51 (0.38, 0.65)
Sensitivity	90.64 (84.90, 96.38)	82.58 (72.15, 93.00)	69.37 (53.30, 85.43)	87.92 (80.13, 95.72)	68.90 (52.79, 85.01)	85.87 (77.82, 93.92)	91.31 (86.69, 95.93)	94.98 (91.50, 98.44)	70.48 (54.76, 86.20)	96.27 (91.62, 100.00)	73.19 (60.55, 85.83)
1-Specificity	15.58 (6.58, 24.58)	13.89 (4.47, 23.32)	8.20 (0.00, 17.75)	36.86 (17.83, 55.89)	8.24 (0.00, 17.84)	19.99 (8.72, 31.27)	33.75 (17.23, 50.26)	35.78 (19.44, 52.13)	11.52 (2.38, 20.66)	2.06 (0.00, 4.26)	15.87 (6.72, 25.02)
Youden's Index	75.06 (66.47, 83.64)	68.68 (55.35, 82.02)	61.17 (44.58, 77.77)	51.06 (33.12, 69.00)	60.66 (43.94, 77.38)	65.88 (55.38, 76.37)	57.56 (41.50, 73.63)	59.19 (42.22, 76.15)	58.96 (42.92, 74.99)	94.21 (89.26, 99.15)	57.32 (44.16, 70.48)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Table 7

Validity of Accelerometer Measures for Assessment of the Sedentary Time within SB-bout Using a New Algorithm

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	7.51 (2.62, 12.41)	12.17 (5.58, 18.77)	29.74 (12.94, 46.54)	20.39 (0.00, 44.75)	30.31 (13.45, 47.18)	17.59 (8.64, 26.55)	22.03 (0.00, 48.51)	24.17 (0.00, 55.97)	29.53 (14.52, 44.54)	5.23 (0.76, 9.70)	21.56 (10.26, 32.85)
% of bias	-3.50 (-10.28, 3.28)	-9.82 (-18.14, -1.49)	-29.69 (-46.53, -12.85)	4.42 (-23.68, 32.53)	-30.27 (-47.17, -13.38)	-10.85 (-24.09, 2.40)	9.73 (-20.19, 39.65)	17.91 (-15.89, 51.71)	-26.61 (-44.12, -9.09)	-4.09 (-9.11, 0.94)	-18.82 (-32.33, -5.31)
Second-by-second level											
Phi-coefficient	0.74 (0.66, 0.82)	0.62 (0.52, 0.72)	0.55 (0.38, 0.73)	0.56 (0.42, 0.70)	0.55 (0.37, 0.72)	0.62 (0.53, 0.72)	0.62 (0.49, 0.75)	0.65 (0.51, 0.80)	0.53 (0.36, 0.71)	0.90 (0.82, 0.97)	0.53 (0.41, 0.64)
Sensitivity	90.01 (84.87, 95.15)	79.88 (70.33, 89.42)	67.08 (51.22, 82.95)	82.39 (74.27, 90.52)	66.54 (50.61, 82.48)	79.64 (71.16, 88.12)	87.26 (82.10, 92.42)	91.82 (88.36, 95.28)	68.21 (52.46, 83.97)	94.62 (89.91, 99.33)	72.44 (59.70, 85.18)
1-Specificity	13.11 (6.65, 19.57)	12.39 (5.51, 19.27)	7.10 (0.77, 13.42)	23.82 (11.02, 36.62)	6.94 (0.68, 13.20)	13.07 (5.95, 20.19)	22.67 (10.30, 35.05)	25.85 (11.98, 39.72)	10.09 (2.93, 17.25)	2.06 (0.59, 3.53)	15.08 (7.83, 22.33)
Youden's Index	76.90 (70.01, 83.78)	67.49 (56.27, 78.72)	59.99 (44.08, 75.90)	58.57 (44.67, 72.48)	59.60 (43.64, 75.57)	66.57 (57.15, 75.99)	64.59 (52.16, 77.02)	65.97 (51.41, 80.53)	58.12 (42.06, 74.19)	92.56 (87.56, 97.56)	57.36 (45.77, 68.95)

Note. Values are presented as *Mean* (95% CI); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Table 8

Validity of Accelerometer Measures for Assessment of the Sedentary Breaks within SB-bout Using a New Algorithm

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	43.24 (25.44, 61.05)	81.85 (22.15, 141.54)	74.66 (0.00, 151.49)	224.46 (81.93, 366.99)	74.03 (0.00, 150.64)	175.70 (73.04, 278.37)	207.37 (62.05, 352.68)	181.86 (43.31, 320.41)	65.64 (5.32, 125.96)	54.32 (10.11, 98.54)	62.34 (32.11, 92.56)
% of bias	1.76 (-33.51, 37.03)	80.92 (20.59, 141.23)	40.21 (-48.50, 128.91)	224.46 (81.93, 366.99)	42.37 (-45.37, 130.11)	170.29 (63.20, 277.39)	207.37 (62.05, 352.68)	181.86 (43.31, 320.41)	38.20 (-32.88, 109.29)	53.47 (8.75, 98.20)	-19.61 (-71.1, 31.89)
Second-by-second level											
Phi-coefficient	0.44 (0.28, 0.61)	0.29 (0.14, 0.44)	0.22 (0.09, 0.36)	0.31 (0.21, 0.41)	0.23 (0.09, 0.37)	0.35 (0.20, 0.49)	0.43 (0.34, 0.53)	0.46 (0.37, 0.55)	0.23 (0.12, 0.34)	0.71 (0.61, 0.82)	0.18 (0.00, 0.37)
Sensitivity	48.20 (26.68, 69.71)	43.70 (20.68, 66.74)	28.38 (10.10, 46.66)	60.59 (40.96, 80.21)	29.27 (10.64, 47.91)	61.59 (36.87, 86.32)	76.93 (61.99, 91.87)	77.58 (63.71, 91.45)	28.60 (13.83, 43.37)	87.55 (77.27, 97.82)	16.07 (0.00, 33.23)
1-Specificity	1.76 (0.70, 2.80)	3.46 (2.56, 4.35)	2.56 (1.13, 3.98)	7.66 (4.33, 10.99)	2.61 (1.18, 4.03)	6.23 (3.26, 9.20)	6.12 (3.93, 8.30)	4.87 (3.30, 6.45)	2.59 (1.29, 3.88)	1.36 (0.67, 2.05)	1.54 (0.55, 2.53)
Youden's Index	46.64 (25.58, 67.70)	40.32 (17.54, 63.10)	25.57 (7.98, 43.16)	54.08 (34.85, 73.30)	26.4 (8.41, 44.40)	55.71 (29.76, 81.67)	71.49 (55.99, 86.98)	72.78 (58.67, 86.89)	25.75 (11.46, 40.05)	86.05 (75.52, 96.58)	14.38 (0.00, 31.19)

Note. Values are presented as *Mean* (*95% CI*); *MAPE* = mean absolute percentage error (%)

Discussion

SB is a growing public health concern that is significantly associated with chronic diseases and mortality (Katzmarzyk & Lee, 2012; Owen, 2012), requiring the field to have a valid measure of SB. This study investigated the validity of different types of accelerometer measures to identify SB and SB-bout that was estimated using a new algorithm against to the proxy of direct observation of SB in a free-living environment. In general, the findings of this study indicated that activPal, which is primarily developed for the classification of body posture, performed the best with accurate and precise estimates of SB parameters when compared with the criterion. Actigraph GT3X demonstrated the improved performance for the classification of SB specifically when applying the Sojourn method for the second-by-second activity counts from three axes compared with the single axis, thresholds-based GT3X measures. Another important finding of this study is that the likelihood of misclassification of SB using Actigraph accelerometer could possibly be minimized by restricting sedentary bouts when operationalizing the sedentary time. Meanwhile, the performance of the new algorithm to identify SB-bout was varied across different accelerometer measures. The use of activPal in combination with the new algorithm was accurate and precise in estimating SB-bout parameters. The followings are the detailed discussion on the important findings of current study.

Validity of Accelerometers Measures to Identify SB

The accelerometer has been increasingly used for quantifying SB in a free-living environment and has been advocated compared with the subjective measures of SB (e.g., questionnaire). However, a current concern that still remains unclear is related to the validity of different types of accelerometer to identify SB, that is conceptually characterized by two primary components, body posture (i.e., sitting or reclining) and energy expenditure (i.e., <1.5 MET).

In this study, we investigated the validity of three accelerometers (Actigraph GT3X, activPal, and Armband) with different functional characteristics (i.e., posture classification and energy expenditure classification) to identify SB compared with the proxy of direct observation using the automated wearable camera in a free-living setting. The results of current study indicated, on average, that the estimated total time spent in SB from all accelerometer measures was not significantly different compared with the criterion with this modest sample size. However, the amount of mean differences in total sedentary time of each accelerometer measure at the individual level expressed as MAPE (%) ranged from the smallest of 4.11% for activPal to the largest of 25.15% in GT3X-<150cpm. In addition, the inclinometer-based GT3X measures and Armband significantly underestimated the actual total sedentary time compared to the criterion.

Our findings are generally aligned with previous reports that suggest that the activPal is the most accurate and precise measure of SB among adults. Grant, Ryan, Tigbe, and Granat (2006) examined the validity of activPal accelerometer during everyday activities including SB (e.g., watching TV) compared with the direct observation in the controlled and daily living settings. The results highlighted that the activPal correctly classified SB with high sensitivity of 99.7% and 99.5% in a controlled and daily living settings, respectively. Another recent study (Kozey-Keadle et al., 2011) comparing the performance of Actigraph GT3X and activPal accelerometers for the assessment of SB in comparison with the direct observation in a free-living environment also reported that the activPal is the most accurate and precise monitoring device that is sensitive enough to detect changes in total sedentary time.

However, our findings, after restricting certain bout conditions when operationalizing the sedentary time, showed reduced performance of activPal for correctly identifying true time intervals of structured SB at given bout conditions. Although the changes in sensitivity and 1-specificity across different bout conditions were not statistically significant in this modest sample size, this could be of vital importance since the failure to detect true structured SB might increase the number of sedentary events, one of the possible indicators for the patterns of how the sedentary time is accumulated. As shown in Table 3, the number of sedentary events from activPal was 18.18 (95% CI = 12.73, 23.64) which is greater than the criterion (n = 13.27; 95% CI = 9.44, 17.11) and hence reduced the average duration of sedentary bout. However, considering the high sensitivity and specificity of the activPal and its high accuracy for estimating total sedentary time, it is legitimate to speculate that the duration of misclassification is relatively short that could possibly be minimized by increasing the minimum period of upright period. Our results were based on the default setting of minimum period of 10 seconds (possible range from 1 through 100 seconds) for both sitting and upright; however, changes in these parameters could possibly influence the performance of activPal to correctly identify the time spent in structured SB which may also affect the estimates of the pattern of sedentary time accumulation (Alghaeed et al., 2013).

A continuous effort has been made to refine the methods to identify SB using energy expenditure classification devices. Specifically, several different thresholds have been proposed for Actigraph accelerometer particularly focusing on the vertical accelerations that might correspond to <1.5 MET; however, the findings were generally inconsistent. For instance, the threshold of <100 cpm has been extensively used for quantifying the time spent in SB in the studies ranging from a clinical to a large scale epidemiological study (Healy, Matthews, et al., 2011; Matthews et al., 2008). However, the findings from Kozey-Keadle et al. (2011) using Actigraph GT3X accelerometer with the low-frequency extension demonstrated that the threshold of <150 cpm produced the most accurate estimate of total sedentary time (mean error 1.8%) compared with the direct observation while the threshold of <100 cpm showed significant underestimation (mean % of bias -4.9%). Meanwhile, Crouter et al. (2013) reported that the threshold of <50 cpm for the Actigraph GT1M accelerometer in a free-living setting was within 1.8% of measured sedentary time while <8 counts per 10 seconds, which might be theoretically identical to <50 cpm, resulted in 20.8% of sedentary time compared to the estimated sedentary time using <1.5 MET from the Cosmed K4b2 (Cosmed, S.R.L., Italy).

In present study, we found that the average total sedentary time estimated from threshold-based GT3X measures were comparable to the criterion. However, the accuracy of the estimates was largely varied by the individual differences, as depicted by the relatively wide range of 95% CIs in MAPE and % of bias for those measures. This may imply that the ability of threshold-based GT3X measures to classify SB might be influenced by unidentified random errors at the individual level that may worsen the precision of the estimates (Kozey-Keadle et al., 2011).

It is also worthwhile to note that the sensitivity was slightly improved by increasing the thresholds for GT3X measure, which also resulted in the increased ratios of misclassification (1-specificity) of sedentary time. The threshold-based GT3X measures rely on the vertical accelerations when the device is mounted on waist, that may not be sensitive enough to detect the changes in the posture (e.g., sit to stand and stand to sit) (Granat, 2012; Lyden et al., 2012). Our findings may imply that the increased thresholds would improve the SB assessments of the GT3X accelerometer by identifying possible SB with minimal movements that might increase the accelerations in the vertical axis. However, it should also be noted that it would simultaneously increase the likelihood of misclassification of light-intensity physical activity (e.g., standing still) as sedentary.

The current study extended this finding by restricting the sedentary bouts when operationalizing the sedentary time. Our findings indicated that the increased restrictions on sedentary bout resulted in the reduced ratio of 1-specifitiy. Specifically, the bout condition of ≥900 seconds (15 minutes) for the GT3X-<150cpm dramatically reduced the 1-specificity from 32.20% (95% CI = 18.68, 45.71) for No-restriction to 8.92% (95% CI = 0.00, 20.78) while the changes in sensitivity was minimal (93.03% for No-restriction and 90.56% for ≥900-sec bout condition). This may be of vital importance for a study that examines the dose-response relationship between sedentary time and health outcomes using Actigraph accelerometer. In a recent study that examined the influence of sedentary bout on the relationship between the sedentary time and metabolic risk factors using the NHANES 2003-2005 accelerometer data (Actigraph model 7164), the short bout (<10 minute) of sedentary time were, in general, positively associated with health outcomes while negative associations were observed in the longer bout of sedentary time when using the threshold of <100 cpm. We also highlighted that the use of total sedentary time without bout restrictions significantly influenced the implications of the relationship with health outcomes (e.g., no significant association with BMI when using total sedentary time, but significant and negative association with BMI in the longer sedentary bout).

Restricting sedentary bout may limit the operational definition of sedentary time to be the time spent in the structured SB at given sedentary bout condition. However, considering that the possible dose-response relationship of longer sedentary bout and health outcomes are previously documented using activPal accelerometer (Chastin & Granat, 2010), it could be a legitimate approach to extract the longer sedentary bout from GT3X measure when using the threshold approach in order to minimize the measurement errors.

Meanwhile, several updates have been made to the Actigraph accelerometer. Specifically, the inclinometer function enables the GT3X device to measure posture when the device is worn perfectly vertical on the hip. In the present study, the inclinometer-based GT3X measures significantly underestimated total sedentary time regardless of the epoch lengths compared with the criterion. Furthermore, while 1-specificity for all epoch lengths were relatively lower (13.50% - 14.19%) compared to the threshold-based GT3X measures, sensitivity (73.97% - 74.35%) was significantly lower than GT3X-<100 cpm (90.50%) and GT3X-<150 cpm (93.03%). Our findings are aligned with the previous reports that indicated low accuracy of inclinometer function in the GT3X. In a study conducted by Carr and Mahar (2012) that examined the validity of Actigraph GT3X+ measures including the inclinometer outputs for identification of SB and light-intensity activity in a controlled setting highlighted that the percentages of correctly classified SB were 66.7%, 63.4%, and 66.2% for lying down, sitting while watching TV, and sitting while working on a computer, respectively. Although the inbuilt inclinometer function in the Actigraph GT3X device can be useful to estimate the possible postural information, its low accuracy and precision should be of concern when measuring SB in a free-living setting.

Recently, an advanced statistical approach based on a machine learning technique has been increasingly applied to obtain the accurate and precise level of physical activity including SB from the accelerometer outputs. Lyden et al. (2014) proposed a hybrid machine learning method called Sojourn methods that combines artificial neural network with hand-built decision trees. Sojourn-1x uses the information about the percentage and duration of zero activity counts from the second-by-second vertical axis activity counts. using the decision tree approach, it determines time intervals for sitting/lying still and sitting with minimal movements separated from the standing still and standing with minimal movement. Sojourn-3x uses the percentage of non-zero activity counts from vertical axis to determine time intervals for inactivity. The neural network that was trained to distinguish sedentary from standing in a free-living setting is further applied to estimate the time intervals with SB separated from light-intensity physical activity (i.e.,g standing still and standing with minimal movement) using the second-by-second activity counts from three axes (vertical, anterior-posterior, and medial-lateral).

The methods are primarily aimed to estimate METs from hip-mounted, Actigraph accelerometer outputs; however, the validation results also highlighted that Sojourn methods significantly improved the performance of Actigraph GT3X accelerometer to identify the time spent in SB (mean % of bias of 8.8 and 0.5 for Sojourn-1x and -3x, respectively) compared to the threshold-based (<100 cpm) GT3X measure. In present study, the accuracy and precision of the estimated total sedentary time using the Sojourn methods were relatively higher than other GT3X-measures. Specifically, the misclassification ratio (non-sedentary to sedentary) was relatively lower (1-specificity = 15.16% and 15.44% for GT3X-Soj3x and GT3X-Soj1x, respectively) and the overall performances to identify SB intervals were the second- and third-highest as shown by Youden’s indices of 74.74 (95% CI = 68.05, 81.42) and 65.96% (95% CI = 53.29, 78.63) for GT3X-Soj3x and GT3X-Soj1x, respectively.

Although Sojourn methods showed relatively higher accuracy and precision compared to other GT3X measures, the overall performance to identify true sedentary time intervals while minimizing the misclassification of true non-sedentary time was significantly lower compared to the activPal [Youden’s index of 92.48 (95% CI = 87.26, 97.70)]. However, our analysis after restricting sedentary bouts showed relatively constant sensitivity and decreased in 1-specificity for GT3X-Soj3x. This suggests that the use of Sojourn method in combination with certain bout restriction may improve the accuracy of the time spent in structured SB at any given bout duration that could be comparable to the activPal. Furthermore, considering that the training data that were used to distinguish the sedentary from standing in the neural network analysis for Sojourn-3x was developed among relatively small sample size (6 participants) (Lyden et al., 2014), training the neural network model with a larger sample size with varying patterns of habitual SB in a free-living setting would likely improve the performance of Sojourn-3x when assessing SB.

Validity of Accelerometers Measures to Identify SB-bout using a New Algorithm

There has been increased evidence showing a beneficial association of breaks in SB with various health outcomes (Dunstan et al., 2012; Healy et al., 2008). Specifically, the absolute number of transitions from sedentary to active phase has been extensively used to examine the dose-response association with health outcomes (Healy et al., 2008; Healy, Matthews, et al., 2011); however, this approach has also been questioned. A previous report using the NHANES 2003-2005 accelerometer data indicated that operationalizing the sedentary breaks as an absolute number of transitions from sedentary to active phase is an alternative expression of the number of sedentary bouts that is more relevant to the patterns of how sedentary time is accumulated.

In present study, an algorithm was developed that can readily identify SB-bout in accelerometer data, including the structured sedentary time and possible breaks within the bout. It was our rationale that the interruption in sedentary time would occur within the structured SB-bout. However, the results showed that algorithm worked only for the activPal which led relatively high accuracy and precision in estimating SB parameters. The accuracy and precision for the SB-bouts and sedentary time estimates within the bout from each accelerometer measure were similar to the validity results of respective accelerometer measure without any bout restriction. The findings from this study imply that the ability of the algorithm to accurately estimate sedentary breaks within the bout would likely depend on the validity of each accelerometer to detect the postural differences.

There are several limitations that need to be addressed when interpreting the results. First, the findings were based on the relatively small sample size (11 participants) which might influence on the variations in the estimates due to the sampling error. Second, the use of the Autographer automated wearable camera as the criterion measure might introduce a measurement error due to the time intervals between the images. The Autographer typically captures a maximum of 10 images in a minute and thus it might fail to capture the images at the exact moment when the posture was changed. Although the observed bias was within ±5 second when compared with the direct observation in our preliminary calibration phase, this bias likely influences the sensitivity and 1-specificity estimated from the second-by-second data.

In conclusion, the estimated total sedentary time was not statistically different across different accelerometer measures. However, the GT3X measures based on the thresholds from the vertical axis and the inclinometer function as well as the Armband may not be sensitive enough to detect postural information, increasing the likelihood of misclassification of non-sedentary time. The use of the Sojourn method using activity counts from three axes provides more accurate and precise estimates of sedentary time compared to other GT3X measures; however, the activPal is a more accurate monitoring device when assessing SB. One possible strategy to improve the performance of the thresholds-based GT3X measures would be the restriction of sedentary bout in combination with the threshold of <150 cpm that may decrease the likelihood of misclassification of non-sedentary time. In addition, there are limitations to the new algorithm developed to identify SB-bout since the performance of new algorithm may be significantly influenced by the functional ability of monitoring device used to identify the sedentary behavior from the accelerometer outputs.

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APPENDICES

Appendix A - Informed Consent

KINESMETRICS
MIDDLE TENNESSEE STATE UNIVERSITY

Research Volunteer Information Form

PLEASE READ THE FOLLOWING CAREFULLY

Title:

Development and validation of a new sedentary behavior identification algorithm for accelerometers

What is the study about?

We want to measure how much time you spent on Sedentary Behaviors (e.g., sitting at a desk, driving a car, etc.) in a single day using multiple devices.

We want to compare the accuracy of outcomes (e.g., time spent in sedentary behaviors) across multiple devices.

Who is eligible for participation in this study?

1. Healthy adults, ages between 20 and 60, who are physically and cognitively able to perform normal daily activities.
2. Provide written consent to complete study protocols and willing to comply the study protocols.

What will I be expected to do?

You will be asked to comply with the following procedures:

First visit ⇨ Monitoring Day ⇨ Second visit

1. At the First visit you will be asked to do the following:

- Tell us your job, age, and allow us to measure your height and weight.
- We will introduce the monitoring devices you shall wear during the monitoring day.
  1. Two Actigraph accelerometers
     - The devices will be clipped to a strap around your waist
  2. Sensewear™ Armband
     - This device will be placed over the triceps muscle
  3. ActivPal accelerometer
     - This device will be placed on the mid-anterior position of the right thigh
  4. Autographer - automated wearable camera
     - This device will be placed around the neck using a lanyard
- Tell us the outlines of your activities that may be happened in the upcoming monitoring day.
  - We will discuss the possible locations/situations that you may need to deactivate or remove the Autographer automated wearable camera in your monitoring day.

- We will discuss the ethical directions in using the Autographer automated wearable camera in order to maximize your right and privacy.
- You will take those devices with you when you leave.

2. During the Monitoring Day you will be asked to do the following:

- Place the monitoring devices at the pre-designated body locations as instructed at the first visit, and keep wearing them for approximately 10 consecutive hours, if there are not any issues or concerns during the monitoring day.
- You do not have to change the patterns of your daily activities during the monitoring day.
- If you have any issues in wearing the monitoring devices, you are always welcome to stop wearing the devices.
- Be aware of the locations/situations where you are instructed to deactivate or remove the Autographer devices in the monitoring day.

  A list of places and situations in which we ask you to remove or deactivate the Autographer
  - Any restroom
  - Any changing room, locker room (e.g., house, gym), etc.
  - Doctor's office/Hospital/Medical Center
  - Banks/ATM
  - Schools/Government Buildings
  - Whenever/Wherever you would prefer for images not to be captured
  - Whenever/Wherever anyone requests deactivating or removing

3. At the Second visit you will be asked to do the following:

- Return the devices and tell us any issues you might have during the monitoring day.
- Review the images captured by Autographer camera during the monitoring day in privacy. At this time, you will be able to review and delete some images you might wish to delete.

What are the potential risks to me of taking part?

The images captured by the Autographer automated wearable camera may be unwanted or unflattering.

1. A maximum 10 images will be captured in a minute during the monitoring day and will depict where you go, what you do, and for how long.
2. Participants can forget they are wearing the device and record unwanted and unflattering images (e.g., bathroom visits, online banking).
3. Data of illegal activities may not be protected by confidentiality and may be passed to law enforcement depending on the nature of the activity.
4. Images of Third Parties may be captured which could subject the participant to liability for invasion of privacy or similar claims.
5. Participants will not get copies of their images.
6. Participants may also experience physical discomfort from wearing the devices.

Although the participant may not have as much control for the automatically capture images during the measurement sessions, following components will be secured in order to protect your privacy and confidentiality.

1. No individual will be identifiable in any research dissemination.
2. The images will be stored in the USB flash drive. The password protection to access the USB flash drive will be secured. The USB flash drive will be kept in a locked file cabinet or cupboard along with other documents.

3. Participants will review (and delete if necessary) their images in privacy.
4. Participants are able to remove the device or temporarily pause image capture whenever they wish.
5. Only a team of specifically trained researchers will have access to the image data.
6. A reference card will be provided for you to carry around while wearing the device.

What else do I need to know about wearing the Autographer camera?

Although it is not practical or necessary to obtain informed consent from the people in public spaces when wearing the wearable camera, we would like you to know following information:

1. You may need to be prepared for questions by the public with a short sentence that explains the device and concludes with an offer to remove the device if they are feeling uncomfortable.
2. You should remove device in any situation where it is attracting unwanted attention, or you feel threatened or uneasy wearing the device.
3. You may need to seek verbal permission from family members and cohabitants before study commencement.
4. You should inform friends and acquaintances of device when encountered and offer to remove device if they are uncomfortable.
5. You should inform third parties that they also can request image deletion by asking you to inform the research team, or contacting them directly.
6. The privacy and anonymity of third parties will be protected. Images will not be published.
7. Employers may not approve of the use of a wearable camera at work. Participants should discuss their participation with their employer before beginning the study.

Do I have to take part?

Involvement in this study is voluntary. No financial compensation is offered.

However, following your participation, we will provide the document that includes:

1) Your time spent in sedentary behaviors during the monitoring day
2) A general information about potential health risks of being sedentary in a modern society
3) Some behavioral strategies to reduce the sedentary time in a daily life.

As a volunteer you are under no obligation to participate or to continue with the study if you do not wish; therefore you can withdraw at any time without penalty.

Will your participation in the research project be kept confidential?

All of the data we collect will be summarized in a final report in which individual responses will be anonymous (your name will not be used in any report of the findings, and there will be no record of your name on the data sheet). Upon completion of the study, all records will be retained and stored by the Department of Health and Human Performance. All signed consent forms will be stored separately to maintain confidentiality.

Who can you contact if you have any questions about the project?	Who can you contact if you have a complaint about the project?
Dr. Minsoo Kang Department Health and Human Performance MTSU Box 96 Murphy Center, Room128 Middle Tennessee State University Phone: 615-904-8426 Fax: 615-898-5020 Email: mkang@mtsu.edu	Dr. Kellie Hilker Compliance Officer Sam H. Ingram Bldg. 010A Middle Tennessee State University Murfreesboro, TN 37132 PH: 615-494-8918 Email: kellie.hilker@mtsu.edu

What next?

- If you are happy to be involved in the study we would ask you to sign the consent form and return it to the researcher. Also, you will be given a copy of this consent form.
- If after reading this information you do not wish to take part you do not have to do anything - Thank you for your time.

Information Card

This card illustrates the answers if someone inquires about the Autographer device.

"I am participating in a study on sedentary behaviors which has been approved by the MTSU IRB. This is a digital camera that automatically captures low-resolution still images throughout the day, which will later be used to describe my behaviors. It does not record audio or full-motion video. Any images captured will not be made public in any fashion and will only be seen by the trained researchers. If you would prefer, I can turn off or temporarily deactivate the camera, and/or make a note the images just taken deleted without anyone seeing them. I can also provide contact information for the researchers."

List of the places that you should NOT use the camera

- Any restroom
- Any changing room, locker room (e.g., house, gym), etc.
- Doctor's office/Hospital/Medical Center
- Banks/ATM
- Schools/Government Buildings
- Whenever/Wherever you would prefer for images not to be captured
-Whenever/Wherever anyone requests deactivating or removing

Contact information:

Youngdeok Kim
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Dr. Minsoo Kang
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Phone: 615-904-8426
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Dr. Kellie Hilker
Compliance Officer
Phone: 615-494-8918
Email: kellie.Hilker@mtsu.edu

To share with the people (e.g., employer, family)

He/She is participating in a study on sedentary behaviors which has been approved by the MTSU Institutional Review Board (IRB). This study are 1) to measure the time spent in sedentary behaviors (e.g., sitting at a desk, driving a car, etc.) in a single day using multiple monitoring devices and 2) to compare the accuracy of outcomes across them.

This participant is wearing four different monitoring devices. Three different types of accelerometer that measure the accelerations caused by any ambulatory movement and one automated wearable camera that automatically captures the maximum of 10 images in a minute.

The images captured by the automated wearable camera may be unflattering that possibly include the images of third parties. However, we will protect the privacy and anonymity of third parties as follow:

1. Third parties can request image deletion by asking the participants to inform the research team, or contacting us directly.
2. Only a team of specifically trained researchers will have access to the image data.
3. The images will be stored in the USB flash drive. The password protection to access the USB flash drive will be secured. The USB flash drive will be kept in a locked file cabinet.
4. Images will not be published in anywhere and be solely used for the IRB approved research questions.

We are greatly appreciated if you shall permit this participant to wear the automated wearable camera.

Should you have any concern or issue, please do not hesitate to contact us.

<u>Contact information:</u>

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Appendix B – IRB Letter of Approval

February 26, 2014

Youngdeok Kim <yk2k@mtmail.mtsu.edu>
Protocol Title: **DEVELOPMENT AND VALIDATION OF A NEW SEDENTARY BEHAVIOR IDENTIFICATION ALGORITHM FOR ACCELEROMETERS**
Protocol Number: 14-166

The MTSU Institutional Review Board has reviewed the research proposal identified above. The MTSU IRB has determined that the study meets the criteria for approval under 45 CFR 46.110 and 21 CFR 56.110 and that you have satisfactorily completed all requested modifications.

Approval is granted for one (1) year from the date of this letter for **30** participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting and analyzing data. Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date. Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will NOT be able to use any data and/or collect any data.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

William Langston
Chair, MTSU Institutional Review Board

Appendix C – Supplemental Tables

Supplemental Table 1

Descriptive Statistics of SB Parameters Across Accelerometer Measures for the Bout Condition of <300 second

	Autographer	GT3X 1-sec epoch			GT3X 10-sec epoch		GT3X 60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-<8cnts/10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Total Sedentary Time (min)	238.00 (173.49, 302.52)	228.21 (165.08, 291.35)	199.23 (143.1, 255.36)	144.68 (96.88, 192.48)	146.19 (98.52, 193.86)	145.86 (98.10, 193.62)	199.41 (142.55, 256.26)	224.66 (172.20, 277.12)	242.84 (193.33, 292.34)	164.61 (112.22, 216.99)	224.01 (162.89, 285.12)	190.86 (133.55, 248.17)
Number of Sedentary Events	8.64 (6.78, 10.50)	9.18 (6.98, 11.39)	12.36 (9.18, 15.55)	9.45 (6.85, 12.06)	13.27 (10.01, 16.54)	9.55 (6.74, 12.35)	13.45 (9.95, 16.96)	12.36 (10.03, 14.70)	12.18 (9.76, 14.60)	9.18 (6.57, 11.80)	10.18 (7.40, 12.97)	7.45 (5.67, 9.24)
Mean Durations (min)	27.75 (20.89, 34.62)	24.84 (19.48, 30.20)	16.03 (13.05, 19.00)	15.24 (12.38, 18.09)	11.11 (8.81, 13.40)	15.34 (12.53, 18.14)	15.11 (11.61, 18.61)	18.42 (14.81, 22.02)	20.53 (16.21, 24.85)	18.12 (14.71, 21.53)	23.53 (15.91, 31.16)	25.86 (18.26, 33.45)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Supplemental Table 2

Descriptive Statistics of SB Parameters Across Accelerometer Measures for the Bout Condition of <600 second

		GT3X 1-sec epoch			GT3X 10-sec epoch		GT3X 60-sec epoch					
	Autographer	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-<8cnts/10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s	activPal	Armband
Total Sedentary Time (min)	220.58 (154.58, 286.58)	208.18 (146.08, 270.28)	158.67 (106.25, 211.09)	117.46 (70.64, 164.27)	85.73 (38.02, 133.44)	119.29 (73.83, 164.75)	158.21 (102.14, 214.29)	190.21 (135.03, 245.39)	212.12 (161.30, 262.95)	143.19 (91.31, 195.07)	201.84 (141.17, 262.51)	220.58 (154.58, 286.58)
Number of Sedentary Events	6.27 (4.71, 7.84)	6.36 (4.79, 7.93)	6.82 (4.76, 8.87)	5.45 (3.26, 7.65)	4.64 (2.28, 6.99)	5.55 (3.46, 7.63)	7.18 (5.15, 9.22)	7.18 (4.96, 9.41)	7.45 (5.85, 9.05)	6.09 (4.02, 8.16)	7.09 (5.20, 8.98)	5.91 (4.10, 7.72)
Mean Durations (min)	34.99 (28.43, 41.55)	32.56 (26.36, 38.77)	23.46 (18.92, 27.99)	22.32 (18.73, 25.90)	17.11 (14.19, 20.03)	21.52 (17.44, 25.59)	21.41 (17.09, 25.72)	27.51 (21.91, 33.12)	29.01 (23.24, 34.78)	23.18 (19.30, 27.05)	29.18 (22.16, 36.20)	32.33 (23.18, 41.48)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Supplemental Table 3

Descriptive Statistics of SB Parameters Across Accelerometer Measures for the Bout Condition of <900 second

	Autographer	GT3X 1-sec epoch			GT3X 10-sec epoch		GT3X 60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-<8cnts/10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Total Sedentary Time (min)	202.95 (134.09, 271.81)	188.41 (122.93, 253.9)	123.48 (73.61, 173.36)	88.62 (48.31, 128.93)	58.22 (17.03, 99.42)	89.42 (49.06, 129.77)	129.17 (72.42, 185.92)	171.64 (116.10, 227.17)	192.55 (138.4, 246.71)	119.71 (69.26, 170.15)	171.83 (108.29, 235.38)	160.90 (106.96, 214.84)
Number of Sedentary Events	4.82 (3.23, 6.40)	4.73 (3.00, 6.46)	4.00 (2.56, 5.44)	3.09 (1.58, 4.61)	2.36 (0.68, 4.04)	3.09 (1.58, 4.61)	4.73 (3.03, 6.43)	5.45 (3.72, 7.19)	5.73 (4.13, 7.32)	4.18 (2.29, 6.08)	4.64 (2.98, 6.29)	4.82 (3.23, 6.40)
Mean Durations (min)	41.87 (36.65, 47.10)	40.48 (35.67, 45.28)	30.23 (25.47, 34.98)	30.70 (25.69, 35.71)	24.88 (22.09, 27.67)	31.03 (25.93, 36.14)	25.64 (21.77, 29.52)	31.60 (27.15, 36.04)	34.46 (28.75, 40.17)	28.65 (24.08, 33.21)	37.64 (29.57, 45.70)	41.87 (36.65, 47.10)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Supplemental Table 4

Descriptive Statistics of SB Parameters Across Accelerometer Measures for the Bout Condition of <1200 second

	Autographer	GT3X 1-sec epoch			GT3X 10-sec epoch		GT3X 60-sec epoch				activPal	Armband
		GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-<8cnts/10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Total Sedentary Time (min)	184.86 (118.34, 251.37)	171.38 (111.37, 231.39)	105.03 (58.09, 151.98)	64.84 (34.24, 95.45)	42.55 (10.77, 74.34)	67.33 (36.49, 98.18)	90.59 (37.03, 144.15)	132.42 (81.62, 183.22)	152.78 (102.27, 203.30)	96.05 (55.06, 137.03)	147.59 (89.98, 205.21)	147.62 (92.63, 202.61)
Number of Sedentary Events	3.82 (2.35, 5.28)	3.73 (2.38, 5.07)	2.91 (1.73, 4.09)	1.73 (0.82, 2.63)	1.45 (0.32, 2.59)	1.82 (0.93, 2.71)	2.45 (1.00, 3.91)	3.18 (1.95, 4.41)	3.45 (2.40, 4.51)	2.73 (1.45, 4.01)	3.27 (2.07, 4.48)	3.82 (2.35, 5.28)
Mean Durations (min)	49.66 (39.82, 59.50)	46.14 (39.60, 52.68)	35.69 (32.49, 38.89)	39.84 (32.05, 47.62)	30.24 (24.27, 36.20)	38.07 (32.52, 43.62)	36.37 (31.51, 41.24)	42.04 (35.06, 49.02)	44.54 (37.54, 51.53)	37.22 (31.78, 42.65)	46.69 (30.79, 62.59)	49.66 (39.82, 59.50)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior

Supplemental Table 5

Validity of Accelerometer Measures for the Assessment of SB for the Bout Condition of < 300 second

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	7.04 (1.84, 12.25)	15.47 (8.63, 22.32)	34.96 (17.86, 52.06)	36.92 (25.58, 48.25)	34.54 (17.67, 51.40)	17.26 (10.33, 24.20)	17.28 (0.00, 34.63)	20.87 (-10.88, 52.63)	30.12 (15.29, 44.94)	5.74 (0.86, 10.61)	21.71 (9.88, 33.55)
% of bias	-2.91 (-9.80, 3.98)	-15.33 (-22.33, -8.34)	-34.91 (-52.06, -17.76)	-36.92 (-48.25, -25.58)	-34.49 (-51.40, -17.59)	-14.70 (-24.12, -5.28)	2.29 (-18.84, 23.43)	14.88 (-18.51, 48.26)	-26.52 (-44.44, -8.60)	-5.18 (-10.35, 0.00)	-17.96 (-32.59, -3.33)
Second-by-second level											
Phi-coefficient	0.76 (0.68, 0.84)	0.60 (0.51, 0.69)	0.56 (0.38, 0.73)	0.47 (0.36, 0.58)	0.56 (0.39, 0.73)	0.61 (0.49, 0.73)	0.67 (0.57, 0.78)	0.70 (0.57, 0.82)	0.54 (0.38, 0.70)	0.89 (0.81, 0.96)	0.52 (0.41, 0.63)
Sensitivity	90.46 (85.07, 95.84)	76.08 (67.19, 84.96)	63.11 (46.83, 79.40)	56.76 (45.48, 68.03)	63.53 (47.50, 79.56)	75.64 (65.75, 85.53)	86.58 (81.81, 91.35)	92.24 (89.53, 94.95)	68.02 (52.50, 83.53)	93.82 (88.89, 98.76)	72.13 (59.10, 85.15)
1-Specificity	12.35 (6.63, 18.06)	10.33 (4.49, 16.18)	3.39 (0.14, 6.65)	5.38 (0.29, 10.48)	3.39 (0.16, 6.62)	9.60 (3.60, 15.58)	15.24 (5.75, 24.74)	20.63 (6.93, 34.32)	8.93 (3.43, 14.43)	1.61 (0.40, 2.82)	15.73 (7.94, 23.52)
Youden's Index	78.11 (71.34, 84.88)	65.74 (55.75, 75.73)	59.72 (43.36, 76.08)	51.37 (39.16, 63.59)	60.14 (44.14, 76.14)	66.04 (53.60, 78.48)	71.34 (61.67, 81.00)	71.61 (58.34, 84.88)	59.08 (44.44, 73.72)	92.21 (87.19, 97.23)	56.40 (44.71, 68.08)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Supplemental Table 6

Validity of Accelerometer Measures for the Assessment of SB for the Bout Condition of < 600 second

	1-sec epoch			10-sec epoch		60-sec epoch					
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s	activPal	Armband
Aggregated level											
MAPE (%)	8.02 (2.65, 13.39)	28.29 (18.08, 38.51)	41.56 (20.55, 62.57)	61.43 (45.01, 77.86)	40.70 (20.56, 60.84)	28.07 (14.49, 41.64)	22.35 (9.37, 35.33)	22.88 (0.00, 54.81)	35.50 (18.45, 52.55)	8.88 (3.23, 14.54)	29.15 (18.15, 40.14)
% of bias	-4.20 (-11.41, 3.01)	-28.29 (-38.51, -18.08)	-41.55 (-62.57, -20.52)	-61.43 (-77.86, -45.01)	-40.70 (-60.84, -20.55)	-27.93 (-41.64, -14.23)	-8.70 (-28.16, 10.77)	8.94 (-26.26, 44.14)	-30.34 (-51.77, -8.91)	-7.23 (-13.96, 0.00)	-15.12 (-35.83, 5.60)
Second-by-second level											
Phi-coefficient	0.80 (0.71, 0.90)	0.58 (0.47, 0.71)	0.57 (0.37, 0.76)	0.41 (0.28, 0.55)	0.50 (0.27, 0.73)	0.61 (0.48, 0.75)	0.71 (0.63, 0.80)	0.74 (0.63, 0.85)	0.48 (0.27, 0.70)	0.87 (0.79, 0.95)	0.57 (0.45, 0.68)
Sensitivity	91.14 (85.02, 97.26)	68.26 (57.16, 79.36)	56.36 (36.33, 76.39)	38.34 (21.79, 54.89)	56.67 (36.77, 76.57)	67.61 (52.88, 82.34)	81.99 (71.28, 92.71)	89.65 (85.08, 94.22)	62.13 (43.15, 81.11)	91.30 (84.91, 97.69)	73.08 (58.67, 87.49)
1-Specificity	8.01 (2.44, 13.59)	6.31 (0.00, 12.7)	2.59 (0.00, 5.62)	0.09 (0.00, 0.27)	3.24 (0.14, 6.34)	3.13 (0.05, 6.20)	5.85 (0.44, 11.26)	12.08 (0.00, 24.71)	9.10 (2.85, 15.35)	1.33 (0.24, 2.43)	13.99 (5.00, 22.97)
Youden's Index	83.13 (74.72, 91.54)	61.94 (50.04, 73.85)	53.77 (33.58, 73.96)	38.25 (21.65, 54.86)	53.42 (32.42, 74.43)	64.48 (48.78, 80.19)	76.14 (66.15, 86.13)	77.57 (65.86, 89.28)	53.03 (34.23, 71.83)	89.97 (83.20, 96.73)	59.10 (46.87, 71.32)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Supplemental Table 7

Validity of Accelerometer Measures for the Assessment of SB for the Bout Condition of < 900 second

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	6.44 (0.00, 12.92)	37.70 (24.10, 51.31)	53.09 (30.57, 75.61)	69.22 (50.54, 87.89)	52.78 (30.33, 75.23)	36.29 (20.76, 51.82)	23.99 (7.99, 39.98)	26.89 (0.00, 67.24)	45.98 (24.31, 67.65)	14.73 (4.27, 25.19)	28.61 (14.02, 43.20)
% of bias	-6.03 (-12.70, 0.64)	-37.60 (-51.35, -23.84)	-53.07 (-75.61, -30.54)	-69.22 (-87.89, -50.54)	-52.78 (-75.23, -30.33)	-36.29 (-51.82, -20.76)	-7.80 (-30.58, 14.58)	11.58 (-32.24, 55.41)	-36.38 (-65.74, -7.02)	-14.65 (-25.17, -4.14)	-11.16 (-34.77, 12.45)
Second-by-second level											
Phi-coefficient	0.83 (0.72, 0.94)	0.58 (0.45, 0.71)	0.56 (0.35, 0.76)	0.50 (0.27, 0.65)	0.56 (0.35, 0.76)	0.65 (0.51, 0.78)	0.75 (0.66, 0.85)	0.78 (0.66, 0.91)	0.47 (0.25, 0.70)	0.83 (0.71, 0.95)	0.61 (0.45, 0.76)
Sensitivity	91.07 (83.97, 98.16)	61.19 (47.48, 74.89)	46.33 (24.33, 68.32)	30.75 (12.12, 49.39)	46.65 (24.71, 68.59)	63.68 (48.16, 79.2)	82.80 (73.37, 92.22)	90.56 (85.20, 95.95)	54.49 (31.26, 77.71)	84.69 (73.82, 95.56)	76.35 (60.83, 91.87)
1-Specificity	5.93 (1.56, 10.3)	3.58 (0.00, 8.05)	0.52 (0.00, 1.05)	0.00 (0.00, 0.01)	0.50 (0.00, 1.01)	0.00 (0.00, 0.01)	4.14 (0.00, 9.44)	8.92 (0.00, 20.78)	7.33 (2.67, 11.98)	0.82 (0.00, 1.76)	12.72 (3.31, 22.13)
Youden's Index	85.14 (75.82, 94.45)	57.61 (44.33, 70.89)	45.81 (24.13, 67.49)	30.75 (12.12, 49.39)	46.15 (24.52, 67.78)	63.68 (48.16, 79.19)	78.66 (70.01, 87.31)	81.65 (69.67, 93.64)	47.16 (26.01, 68.31)	83.87 (72.55, 95.19)	63.63 (48.30, 78.96)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Supplemental Table 8

Validity of Accelerometer Measures for the Assessment of SB for the Bout Condition of < 1200 second

	1-sec epoch			10-sec epoch		60-sec epoch				activPal	Armband
	GT3X-Soj3x	GT3X-Soj1x	GT3X-Incli-1s	GT3X-8cnts<10s	GT3X-Incli-10s	GT3X-<50cpm	GT3X-<100cpm	GT3X-<150cpm	GT3X-Incli-60s		
Aggregated level											
MAPE (%)	7.88 (1.05, 14.71)	43.60 (25.87, 61.32)	60.25 (38.30, 82.19)	73.44 (56.09, 90.78)	59.16 (37.44, 80.89)	50.97 (28.43, 73.50)	24.06 (10.32, 37.79)	27.22 (3.02, 51.42)	46.73 (22.80, 70.65)	17.60 (5.09, 30.11)	35.55 (17.90, 53.20)
% of bias	-4.79 (-12.92, 3.33)	-43.49 (-61.34, -25.64)	-60.23 (-82.20, -38.27)	-73.44 (-90.78, -56.09)	-59.12 (-80.90, -37.34)	-50.97 (-73.50, -28.43)	-24.06 (-37.79, -10.32)	-4.44 (-35.17, 26.28)	-45.31 (-70.55, -20.07)	-17.52 (-30.09, -4.95)	-7.22 (-37.45, 22.99)
Second-by-second level											
Phi-coefficient	0.80 (0.69, 0.92)	0.59 (0.45, 0.74)	0.51 (0.30, 0.72)	43.84 (24.80, 62.88)	0.52 (0.31, 0.73)	0.62 (0.45, 0.80)	0.74 (0.60, 0.88)	0.75 (0.61, 0.88)	0.55 (0.38, 0.73)	0.77 (0.60, 0.94)	0.58 (0.39, 0.76)
Sensitivity	89.34 (81.66, 97.02)	55.46 (37.86, 73.07)	39.18 (17.81, 60.54)	26.53 (9.23, 43.84)	40.27 (19.10, 61.44)	49.00 (26.48, 71.52)	75.12 (61.28, 88.95)	82.63 (71.25, 94.01)	49.70 (28.06, 71.34)	79.20 (64.68, 93.72)	73.90 (54.57, 93.23)
1-Specificity	6.71 (2.52, 10.90)	3.16 (0.00, 7.52)	0.40 (0.00, 0.84)	0.00 (0.00, 0.01)	0.40 (0.00, 0.82)	0.00 (0.00, 0.01)	0.86 (0.00, 2.39)	5.29 (0.00, 12.69)	3.97 (0.20, 7.75)	2.21 (0.00, 6.44)	14.07 (4.71, 23.43)
Youden's Index	82.63 (72.84, 92.42)	52.31 (35.35, 69.26)	38.78 (17.69, 59.86)	26.53 (9.23, 43.83)	39.87 (18.98, 60.77)	49.00 (26.48, 71.52)	74.26 (59.79, 88.76)	77.34 (64.47, 90.21)	45.73 (25.50, 65.95)	76.99 (59.96, 94.01)	59.83 (40.75, 78.90)

Note. Values are presented as *Mean* (*95% CI*); SB = sedentary behavior; *MAPE* = mean absolute percentage error (%)

Appendix D – Example Codes

i. An example SAS code to convert the activPal 'Event' data to the second-by-second output

[Codes are similar for other accelerometer data (e.g., Armband), but need to change variable names]

```
%let ID = ID_1_activpal_final;

libname data "C:\YD\0. ActivPal\1. SAS data files";
libname xlsxfile "C:\YD\0. ActivPal\ID_1_EventsData_final.xlsx";

data a;
        set xlsxfile. "ID_1_EventsData$"n(dbSASType=(Time=datetime));
        time_char = input(time,$15.);
        time_num = input(substr(time_char,1,10),15.);
        format time_num datetime19.;
        drop time;
run;

proc sort data=a;by time_num; run;

data _null_;
        set a nobs=nobs;
        by time_num;
        if _n_=1 or _n_=nobs; n+1;
        if n=1 then call symput ("start",time_num);
                else if n=2 then call symput ("last", time_num);
run;

proc contents data=a out=vars (keep=varnum name);run;

data b;
        do time_num=&start to &last by 1;
                output;
        end;
run;

data c;
        merge a (in=event) b ;
        by time_num;
        retain time ActivityCode StepCount;
        rename time_num=time;
        array vars (*) ActivityCode__0_sedentary__1__st CumulativeStepCount;
        array new_vars (*) ActivityCode StepCount;
        if event then do;
                do i=1 to dim(vars);
                        new_vars (i) = vars (i);
                end;
        end;
        after2=lag(time_num);
        diff2=time_num-after2;
        if diff2 = 0 then delete;
        keep time_num ActivityCode StepCount;
run;

data data.&ID;
        set c (rename=(ActivityCode=activpal_activCode));
        if activpal_activCode = 0 then activpal_sed=1;
                else activpal_sed=0;
        if activpal_activCode=. then delete;
        keep time activpal_activCode activpal_sed;
run;
```

ii. An example SAS code to obtain the descriptive statistics for each accelerometer measure

```
libname final "C:\YD\1. Individual Final";

data Total_data;
        set final.id_1_final  final.id_2_final  final.id_3_final
            final.id_4_final  final.id_5_final  final.id_6_final
            final.id_7_final final.id_8_final  final.id_9_final
            final.id_10_final final.id_11_final;
        by id;
run;

%macro dur (sed_var=);
data a;
        set total_data;
        by id paxn;
        if reset then do;
                strt=.;
                begin=.;
                end=.;
                reset=.;
        end;
        retain strt begin end reset;
        if &sed_var = 1 and strt = . then do;
                strt=1;
                begin=paxn;
        end;
        if &sed_var = 0 and reset = . then do;
                reset=1;
                end = paxn;
        end;
        if last.id and &sed_var = 1 then do;
                reset=1;
                end=paxn;
        end;
        duration = end-begin;
        keep id paxn strt begin end reset &sed_var duration;
run;

proc summary data=a;
        var duration; by id;
        output out=b_&sed_var (drop= _type_ _freq_)
                  n=n_&sed_var mean=av_dur_&sed_var;
run;
%mend dur;

%dur (sed_var=acti_10s_sed); %dur (sed_var=acti_incl_10s_sed);
%dur (sed_var=acti_60s_sed); %dur (sed_var=acti_60s_sed150);
%dur (sed_var=acti_60s_sed50); %dur (sed_var=acti_incl_60s_sed);
%dur (sed_var=acti_incl_1s_sed); %dur (sed_var=acti_so3x_sed);
%dur (sed_var=acti_so1x_sed); %dur (sed_var=activpal_sed);
%dur (sed_var=armband_sed); %dur (sed_var=auto_sed);

data final.Ind_num_duration;
        merge b_acti_10s_sed b_acti_incl_10s_sed
               b_acti_60s_sed b_acti_60s_sed150
               b_acti_60s_sed50 b_acti_incl_60s_sed
               b_acti_incl_1s_sed b_acti_so3x_sed
               b_acti_so1x_sed b_activpal_sed
               b_armband_sed b_auto_sed;
        by id;
run;
```

```
%macro descrip (sed_var=);
proc means data=final.ind_num_duration mean clm;
        var n_&sed_var av_dur_&sed_var;
run;
%mend;

%descrip (sed_var=acti_10s_sed); %descrip (sed_var=acti_incl_10s_sed);
%descrip (sed_var=acti_60s_sed); %descrip (sed_var=acti_60s_sed150);
%descrip (sed_var=acti_60s_sed50); %descrip (sed_var=acti_incl_60s_sed);
%descrip (sed_var=acti_incl_1s_sed); %descrip (sed_var=acti_so3x_sed);
%descrip (sed_var=acti_so1x_sed); %descrip (sed_var=activpal_sed);
%descrip (sed_var=armband_sed); %descrip (sed_var=auto_sed);
```

iii. An example SAS code to obtain the agreement statistics for each accelerometer measure

```
%macro agreement (sed_var=);
data b;
        set Total_data;
        if auto_sed = 1 then do;
                if &sed_var = 1 then TP_&sed_var = 1;
                        else if &sed_var = 0 then FN_&sed_var = 1;
        end;
        else if auto_sed = 0 then do;
                if &sed_var = 1 then FP_&sed_var = 1;
                        else if &sed_var = 0 then TN_&sed_var = 1;
        end;
        keep id paxn auto_sed TP_&sed_var FN_&sed_var FP_&sed_var TN_&sed_var;
run;

proc summary data=b noprint n;
        var TP_&sed_var FN_&sed_var FP_&sed_var TN_&sed_var;
        output out=c n=TP_&sed_var FN_&sed_var FP_&sed_var TN_&sed_var;
        by id;
run;

data d_&sed_var;
        set c;
        by id;
        Sensi_&sed_var = TP_&sed_var / (TP_&sed_var+FN_&sed_var)*100;
        Speci_&sed_var = FP_&sed_var / (FP_&sed_var+TN_&sed_var)*100;
        youden_&sed_var = Sensi_&sed_var-Speci_&sed_var;
        keep id Sensi_&sed_var Speci_&sed_var youden_&sed_var;
run;
%mend agreement;

%agreement (sed_var=acti_10s_sed); %agreement (sed_var=acti_incl_10s_sed);
%agreement (sed_var=acti_60s_sed); %agreement (sed_var=acti_60s_sed150);
%agreement (sed_var=acti_60s_sed50); %agreement (sed_var=acti_incl_60s_sed);
%agreement (sed_var=acti_incl_1s_sed); %agreement (sed_var=acti_so3x_sed);
%agreement (sed_var=acti_so1x_sed); %agreement (sed_var=activpal_sed);
%agreement (sed_var=armband_sed);

data final.Ind_agreement;
        merge d_acti_10s_sed  d_acti_incl_10s_sed  d_acti_60s_sed
              d_acti_60s_sed150  d_acti_60s_sed50  d_acti_incl_60s_sed
              d_acti_incl_1s_sed  d_acti_so3x_sed   d_acti_so1x_sed
              d_activpal_sed  d_armband_sed;
        by id;
run;

%macro analysis (sed_var=);
proc means data=final.Ind_agreement mean clm;
```

```
        var Sensi_&sed_var Speci_&sed_var youden_&sed_var;
run;
%mend;

%analysis (sed_var=acti_10s_sed);  %analysis (sed_var=acti_incl_10s_sed);
%analysis (sed_var=acti_60s_sed);  %analysis (sed_var=acti_60s_sed150);
%analysis (sed_var=acti_60s_sed50);  %analysis (sed_var=acti_incl_60s_sed);
%analysis (sed_var=acti_incl_1s_sed);  %analysis (sed_var=acti_so3x_sed);
%analysis (sed_var=acti_so1x_sed);  %analysis (sed_var=activpal_sed);
%analysis (sed_var=armband_sed);


%macro corr_auto_sed (sed_var=);
proc corr data=total_data noprint out=cor1_&sed_var (where=(_type_="CORR"));
        var auto_sed &sed_var;
        by id;
run;

data cor2_&sed_var;
        set cor1_&sed_var (keep=id &sed_var);
        by id;
        if &sed_var ne 1;
run;

proc means data=cor2_&sed_var mean clm;
        var &sed_var;
run;
%mend corr_auto_sed;

%corr_auto_sed (sed_var=acti_10s_sed); %corr_auto_sed (sed_var=acti_incl_10s_sed);
%corr_auto_sed (sed_var=acti_60s_sed); %corr_auto_sed (sed_var=acti_60s_sed150);
%corr_auto_sed (sed_var=acti_60s_sed50); %corr_auto_sed (sed_var=acti_incl_60s_sed);
%corr_auto_sed (sed_var=acti_incl_1s_sed); %corr_auto_sed (sed_var=acti_so3x_sed);
%corr_auto_sed (sed_var=acti_so1x_sed); %corr_auto_sed (sed_var=activpal_sed);
%corr_auto_sed (sed_var=armband_sed);
```

iv. An example SAS code to obtain the mean difference statistics for each accelerometer measure

```
%macro tot_diff (sed_var=);
proc summary data=total_data ;
by id;
var &sed_var;
output out=a_&sed_var (drop= _type_ _freq_)
          sum(&sed_var) = tot_&sed_var;
run;
%mend tot_diff;

%tot_diff (sed_var=acti_10s_sed); %tot_diff (sed_var=acti_incl_10s_sed);
%tot_diff (sed_var=acti_60s_sed); %tot_diff (sed_var=acti_60s_sed150);
%tot_diff (sed_var=acti_60s_sed50); %tot_diff (sed_var=acti_incl_60s_sed);
%tot_diff (sed_var=acti_incl_1s_sed); %tot_diff (sed_var=acti_so3x_sed);
%tot_diff (sed_var=acti_so1x_sed); %tot_diff (sed_var=activpal_sed);
%tot_diff (sed_var=armband_sed); %tot_diff (sed_var=auto_sed);

data final.Ind_diff;
        merge a_acti_10s_sed  a_acti_incl_10s_sed
              a_acti_60s_sed  a_acti_60s_sed150
              a_acti_60s_sed50  a_acti_incl_60s_sed
              a_acti_incl_1s_sed  a_acti_so3x_sed
              a_acti_so1x_sed  a_activpal_sed
              a_armband_sed  a_auto_sed;
        by id;
```

```
        array tot (*) tot_acti_10s_sed tot_acti_incl_10s_sed
                      tot_acti_60s_sed tot_acti_incl_60s_sed
                      tot_acti_60s_sed150 tot_acti_60s_sed50
                      tot_acti_incl_1s_sed tot_acti_so3x_sed
                      tot_acti_so1x_sed tot_activpal_sed
                      tot_armband_sed ;
        array ape (*) ape_acti_10s_sed ape_acti_incl_10s_sed
                       ape_acti_60s_sed ape_acti_incl_60s_sed
                       ape_acti_60s_sed150 ape_acti_60s_sed50
                       ape_acti_incl_1s_sed ape_acti_so3x_sed
                       ape_acti_so1x_sed ape_activpal_sed
                       ape_armband_sed;
        array diff (*) diff_acti_10s_sed diff_acti_incl_10s_sed
                       diff_acti_60s_sed diff_acti_incl_60s_sed
                       diff_acti_60s_sed150 diff_acti_60s_sed50
                        diff_acti_incl_1s_sed diff_acti_so3x_sed
                        diff_acti_so1x_sed diff_activpal_sed
                        diff_armband_sed;

        do i=1 to dim(tot);
                ape (i) = abs(tot(i)- tot_auto_sed)/tot_auto_sed;
                diff (i) = (tot(i) - tot_auto_sed)/tot_auto_sed;
        end;
        keep id tot_acti_10s_sed tot_acti_incl_10s_sed
             tot_acti_60s_sed tot_acti_incl_60s_sed
             tot_acti_60s_sed150 tot_acti_60s_sed50
             tot_acti_incl_1s_sed tot_acti_so3x_sed
             tot_acti_so1x_sed tot_activpal_sed tot_auto_sed
             tot_armband_sed
             ape_acti_10s_sed ape_acti_incl_10s_sed
             ape_acti_60s_sed ape_acti_incl_60s_sed
             ape_acti_60s_sed150 ape_acti_60s_sed50
             ape_acti_incl_1s_sed ape_acti_so3x_sed
             ape_acti_so1x_sed ape_activpal_sed
             ape_armband_sed
             diff_acti_10s_sed diff_acti_incl_10s_sed
             diff_acti_60s_sed diff_acti_incl_60s_sed
             diff_acti_60s_sed150 diff_acti_60s_sed50
             diff_acti_incl_1s_sed diff_acti_so3x_sed
             diff_acti_so1x_sed diff_activpal_sed
             diff_armband_sed;
run;

proc means data=final.Ind_diff mean clm;
        var tot_acti_10s_sed tot_acti_incl_10s_sed
            tot_acti_60s_sed tot_acti_60s_sed150
            tot_acti_60s_sed50 tot_acti_incl_60s_sed
            tot_acti_incl_1s_sed tot_acti_so3x_sed
            tot_acti_so1x_sed tot_activpal_sed tot_auto_sed
            tot_armband_sed
            ape_acti_10s_sed ape_acti_incl_10s_sed
            ape_acti_60s_sed ape_acti_60s_sed150
            ape_acti_60s_sed50 ape_acti_incl_60s_sed
            ape_acti_incl_1s_sed ape_acti_so3x_sed
            ape_acti_so1x_sed ape_activpal_sed
            ape_armband_sed
            diff_acti_10s_sed diff_acti_incl_10s_sed
            diff_acti_60s_sed diff_acti_60s_sed150
            diff_acti_60s_sed50 diff_acti_incl_60s_sed
            diff_acti_incl_1s_sed diff_acti_so3x_sed
            diff_acti_so1x_sed diff_activpal_sed
            diff_armband_sed;
run;
```

v. An example SAS code to apply the bout restriction (<300 second) for each accelerometer measure

```
libname final "C:\YD\1. Individual Final";
libname final_bt "C:\YD\1. Individual Final\1. Sed Bout_sporadic\0. 300 sec";

%let bout = 300;

%macro bout (id=, id_final=, var_name=);
data a;
	set final.&id_final;
	keep id paxn &var_name;
run;

data b;
	set a;
	by id paxn;

	if first.id or stopped then do;
		start=0;
		strt_sed=0;
		end_sed=0;
		stopped=0;
	end;

	retain start strt_sed end_sed stopped diff;

	if &var_name =1 and start=0 then do;
		strt_sed = paxn;
		start=1;
	end;
	if &var_name = 0 and start=1 then do;
		end_sed = paxn;
		stopped=1;
	end;
	if last.id and &var_name = 1 then do;
		end_sed = paxn;
		stopped=1;
	end;

	if stopped ne 1 then delete;

	diff = end_sed-strt_sed;

	if diff <&bout then delete;
run;

data c;
	set b (keep=strt_sed end_sed);
	array bout (*) strt_sed end_sed;
	do i=1 to 2;
		paxn = bout(i);output;
	end;
run;

data d;
	set c;
	if i=2 then do;
		i=0;
		paxn=paxn+1;
	end;
run;
```

```
data _null_;
        set a nobs=nobs;
        by paxn;
        if _n_=1 or _n_=nobs;
        n+1;
        if n=1 then call symput ("start",paxn);
                else if n=2 then call symput ("last", paxn);
run;

data e;
        id=&id;
        do paxn=&start to &last by 1;
                output;
        end;
run;

data f_&var_name;
        merge d (in=event)
                 e;
        by paxn;
        retain id &var_name paxn;
        array vars (*) i;
        array new_vars(*) &var_name;

        if i=1 then do;
                do j=1 to dim(vars);
                new_vars(j) = vars(j);
                end;
        end;
        else if i=0 then do;
                do j=1 to dim(vars);
                new_vars(j) = vars(j);
                end;
        end;
        if &var_name=. then &var_name=0;
        keep id paxn &var_name ;
run;
%mend;

%macro bout_2 (id=, id_final=);
%bout (id = &id ,id_final = &id_final, var_name = acti_10s_sed); %bout (id = &id ,id_final = &id_final, var_name = acti_incl_10s_sed);
%bout (id = &id ,id_final = &id_final, var_name = acti_60s_sed); %bout (id = &id ,id_final = &id_final, var_name = acti_60s_sed150);
%bout (id = &id ,id_final = &id_final, var_name = acti_60s_sed50);
%bout (id = &id ,id_final = &id_final, var_name = acti_incl_60s_sed);
%bout (id = &id ,id_final = &id_final, var_name = acti_incl_1s_sed); %bout (id = &id ,id_final = &id_final, var_name = acti_so3x_sed);
%bout (id = &id ,id_final = &id_final, var_name = acti_so1x_sed); %bout (id = &id ,id_final = &id_final, var_name = activpal_sed);
%bout (id = &id ,id_final = &id_final, var_name = armband_sed); %bout (id = &id ,id_final = &id_final, var_name = auto_sed);

data final_bt.&id_final;
        merge final.&id_final (keep = paxn time)
                 f_acti_10s_sed  f_acti_incl_10s_sed
                 f_acti_60s_sed  f_acti_60s_sed150
                 f_acti_60s_sed50  f_acti_incl_60s_sed
                 f_acti_incl_1s_sed  f_acti_so3x_sed
                 f_acti_so1x_sed  f_activpal_sed
                 f_armband_sed  f_auto_sed;
        by paxn;
run;
%mend;

%bout_2 (id=1, id_final = id_1_final); %bout_2 (id=2, id_final = id_2_final); %bout_2 (id=3, id_final = id_3_final);
%bout_2 (id=4, id_final = id_4_final); %bout_2 (id=5, id_final = id_5_final); %bout_2 (id=6, id_final = id_6_final);
%bout_2 (id=7, id_final = id_7_final); %bout_2 (id=8, id_final = id_8_final); %bout_2 (id=9, id_final = id_9_final);
%bout_2 (id=10, id_final = id_10_final); %bout_2 (id=11, id_final = id_11_final);
```

vi. An example SAS code to obtain SB-bout for each accelerometer measure

```
libname final "C:\YD\1. Individual Final";
libname final_bt "C:\YD\1. Individual Final\0. Sed Bout";

%macro sed (data=, sed =);
%let win1_bout=300; * bout duration in Window1;
%let win1_inter=0; * the number of interruption allowed in Window1;
%let win2_before=300; * the screening period before the respective sec;
%let win2_after=300; * the screening period before the respective sec;
%let win2_pct_sed=0.6; * % of sed min required in Window2;
%let win2_max_br=600; * maximum consecutive sec allowed for breaks in window2;
%let win3_cnt_sed=300; * minimum consecutive sedentary sec in Window 3;
%let win3_after=600; * the screening period after the respecitve sec in Window 3;
%let win3_pct_sed=0.4; * % of sed sec required in Window3;

data data_1;
		retain id paxn &sed;
		set final.&data;
		keep id paxn &sed;
run;

******************** Data Preparation ********************;
proc sort data=data_1;
		by id paxn;
run;

data data_2_1;
		set data_1;
		by id;
		array sw (*) sed_win_b1-sed_win_b&win2_before;
		retain sed_win_b1-sed_win_b&win2_before;
		if first.id then do;
				do i=1 to dim(sw);
						sw(i) = .;
				end;
		end;
		output;
		do i=&win2_before to 2 by -1;
				sw(i) = sw(i-1);
		end;
		sed_win_b1= &sed;
		drop i;
run;

proc sort data=data_1;
		by id descending paxn;
run;

%if &win2_after > &win3_after %then %do;
data data_2;
		set data_1;
		by id;
		array sw (*) sed_win1-sed_win&win2_after;
		retain sed_win1-sed_win&win2_after;
		if first.id then do;
				do i=1 to dim(sw);
						sw(i) = .;
				end;
		end;
		output;
		do i=&win2_after to 2 by -1;
```

```
                sw(i) = sw(i-1);
        end;
        sed_win1= sed;
run;
%end;
%else %do;
data data_2;
        set data_1;
        by id;
        array sw (*) sed_win1-sed_win&win3_after;
        retain sed_win1-sed_win&win3_after;
        if first.id then do;
                do i=1 to dim(sw);
                        sw(i) = .;
                end;
        end;
        output;
        do i=&win3_after to 2 by -1;
                sw(i) = sw(i-1);
        end;
        sed_win1= &sed;
run;
%end;

proc sort data=data_2 (drop=i);
        by id paxn;
run;
******************** End of Data Preparation ********************;

******************** Data Processing Begins ********************;
data data_3;
        merge data_2
                 data_2_1;
        by id paxn;

        if reset then do;
                start=.;
                reset=.;
                stop=.;
                condition2=.;
                sed_bout_strt=.;
                sed_bout_inter=.;
                sed_bout_end=.;
                phase1=.;
                cnt_nonsed1=.;
                breaks=.;
                final_bout_st = .;
                final_bout_end = .;
        end;
        retain start reset stop condition2 sed_bout_strt
                 sed_bout_strt sed_bout_inter sed_bout_end phase1 cnt_nonsed1 breaks
                 final_bout_st final_bout_end;

        if &sed=1 and start=. and sum(of sed_win1-sed_win&win1_bout)>=(&win1_bout-&win1_inter) then do;
                sed_bout_strt = paxn;
                start=1;
        end;
        phase1+start;

        * Start counting the breaks;
        if &sed=0 then non_sed=1;else non_sed=0;
        if phase1 ne . then do;
                breaks+non_sed;
        end;
```

```
		if phase1>&win1_bout-1 then do;
			if &sed ne 1 then cnt_nonsed1+1;
				else cnt_nonsed1=0;
			if cnt_nonsed1=1 then do;
				sed_bout_inter=paxn-1;
			end;
		end;

		if cnt_nonsed1>&win2_max_br then do;
			reset=1;
			stop=1;
			sed_bout_end=sed_bout_inter;
		end;

		if phase1 > &win1_bout then do;
			if sed_win1 = 0 then do;
				pct_win2 = (sum(of sed_win_b1-sed_win_b&win2_before sed_win1-
						sed_win&win2_after)+1)/(&win2_before+&win2_after+1);
				pct_win3 = (sum(of sed_win1-sed_win&win3_after))/&win3_after;
				if pct_win2<&win2_pct_sed then do;
					if pct_win3<&win3_pct_sed then do;
						if &sed = 0 then do;
							reset=1;
							stop=1;
							sed_bout_end=sed_bout_inter;
						end;
						else do;
							reset=1;
							stop=1;
							sed_bout_end=paxn;
						end;
					end;
				end;
			end;
		end;

		if last.id and &sed=1 then do;
			if reset=. then sed_bout_end=paxn;
			if phase1 ne . then reset=1;
		end;

		if reset = 1 then do;
			dur_sed = sed_bout_end - sed_bout_strt+1;
			breaks_t=breaks;
			final_bout_st = sed_bout_strt;
			final_bout_end = sed_bout_end;
			if &sed = 0 then do;
				breaks_t = breaks_t - cnt_nonsed;
			end;
		end;
		drop sed_win_b1-sed_win_b&win2_before sed_win1-sed_win&win2_after sed_win1-sed_win&win3_after;
	run;

	data data_4;
		set data_3;
		if reset;
		paxn=final_bout_st-1;
		strtpoint = final_bout_st+1;
		endpoint = final_bout_end+1;
		do i = strtpoint to endpoint by 1;
			paxn+1;
			sed_bout=1;
			output;
```

```
		end;
		keep paxn final_bout_st final_bout_end sed_bout;
run;

data data_5;
		set data_3;
		if phase1 > 0 and non_sed = 1 then bout_br=1;
		keep paxn bout_br;
run;

data data_&sed;
		merge data_4
				data_5;
		by paxn;
		sed_bout_&sed = sed_bout;
		if sed_bout = 1 and bout_br = 1 then sed_bout_&sed = 2;
		keep paxn sed_bout_&sed;
run;

%mend sed;

%macro sed_2 (data = );
%sed (data=&data ,sed=acti_10s_sed); %sed (data=&data ,sed=acti_incl_10s_sed);
%sed (data=&data ,sed=acti_60s_sed); %sed (data=&data ,sed=acti_60s_sed150);
%sed (data=&data ,sed=acti_60s_sed50); %sed (data=&data ,sed=acti_incl_60s_sed);
%sed (data=&data ,sed=acti_incl_1s_sed); %sed (data=&data ,sed=acti_so3x_sed);
%sed (data=&data ,sed=acti_so1x_sed); %sed (data=&data ,sed=activpal_sed);
%sed (data=&data ,sed=armband_sed); %sed (data=&data ,sed=auto_sed);

data final_bt.&data;
		merge final.&data (keep = paxn time)
				data_acti_10s_sed data_acti_incl_10s_sed
				data_acti_60s_sed data_acti_60s_sed150
				data_acti_60s_sed50 data_acti_incl_60s_sed
				data_acti_incl_1s_sed data_acti_so3x_sed
				data_acti_so1x_sed data_activpal_sed
				data_armband_sed  data_auto_sed;
		by paxn;
run;
proc datasets lib=work memtype=data kill;
run;
quit;
%mend sed_2;

%sed_2 (data=id_1_final); %sed_2 (data=id_2_final);
%sed_2 (data=id_3_final); %sed_2 (data=id_4_final);
%sed_2 (data=id_5_final); %sed_2 (data=id_6_final);
%sed_2 (data=id_7_final); %sed_2 (data=id_8_final);
%sed_2 (data=id_9_final); %sed_2 (data=id_10_final);
%sed_2 (data=id_11_final);
```

vii. An example R code to create the resulting graphs for each accelerometer measure

```
data <-read.table ('C://YD//1. Individual Final//1. Sed Bout_sporadic//r_graph_sense&spec.txt',sep=",",header=T)

library("ggplot2")
library (gridExtra)

############################################################
# Creating Bar graph for Spensitivity, 1-Specifitiy, and Youden's Index #
#############################################################
```

```
bar.gr <- function (v, title)
 {
  data1 <- subset(data,var==v)

  g1<-ggplot (data=data1, aes (x= condition, y= value, fill=type))+
    geom_bar(stat="identity",position=position_dodge())+
    geom_errorbar(aes (ymax=upper, ymin=lower), stat="identity",width=.2,position=position_dodge(.9),alpha=.2)+
    scale_fill_manual(values=c("grey60","grey"))+
    theme_bw()+theme(legend.position="none")+
    theme(plot.title=element_text(size=25, vjust=2, face="bold"),
          axis.title.x=element_blank(),
          axis.title.y=element_text(size=20),
          axis.text.x=element_text(size=20),
          axis.text.y=element_text(size=20))+
    ggtitle(title)+
    ylab("Probabiliity (%)")+
    ylim(0,100)+
    scale_x_discrete(limits = c("No Restriction","300-sec","600-sec","900-sec","1200-sec"))
  g2<-g1+geom_point(data=data1,mapping=aes(x=condition,y=youden,shape=17, size=15))
  g3.v<-g2+geom_errorbar(data=data1, aes(ymax=upper.y, ymin=lower.y, width=.1,alpha=.3))+
      scale_shape_identity()
  return(g3.v)
 }

# GT3X - 1-sec epoch #
grid.arrange(
 bar.gr(v="acti_so3x_sed", title="GT3X-Soj3x"),
 bar.gr(v="acti_so1x_sed", title="GT3X-Soj1x"),
 bar.gr(v="acti_incl_1s_sed", title="GT3X-Incli-1s"),
 ncol=3)
# GT3X - 10-sec epoch #
grid.arrange(
 bar.gr(v="acti_10s_sed", title="GT3X-8cnts<10s"),
 bar.gr(v="acti_incl_10s_sed", title="GT3X-Incli-10s"),
 ncol=2)
# GT3X - 60-sec epoch #
grid.arrange(
 bar.gr(v="acti_60s_sed50", title="GT3X-<50cpm"),
 bar.gr(v="acti_60s_sed", title="GT3X-<100cpm"),
 bar.gr(v="acti_60s_sed150", title="GT3X-<150cpm"),
 bar.gr(v="acti_incl_60s_sed", title="GT3X-Incli-60s"),
 ncol=4)
# activPal & Armband#
grid.arrange(
 bar.gr(v="activpal", title="activPal"),
 bar.gr(v="armband", title="Armband"),
 ncol=2)

###################
# Creating Bias graph  #
###################

data.bias <-read.table ('C://YD//1. Individual Final//1. Sed Bout_sporadic//r_bias1.txt',sep=",",header=T)

bias.gr <- function (v, title)
{
 g.bias.v <-ggplot (data=subset(data.bias, type==v)) +
     geom_point (stat="identity",aes(y=condition,x=value2, size=6))+
     geom_errorbarh(mapping=aes(y=condition, x=value2, xmax=upper2, xmin=lower2), height=.1)+
     xlim(-100,100)+
     scale_y_discrete(limits = c("1200-sec","900-sec","600-sec","300-sec","No Restriction"))+
     geom_vline(xintercept=0,alpha=.2)+
     ylab("Bout Conditions")+
     xlab("Percentage of Bias (%)")+
```

```
        theme_bw()+theme(legend.position="none")+
        theme(plot.title=element_text(size=25, vjust=2, face="bold"),
            axis.title.x=element_text(size=20, vjust=-0.4),
            axis.title.y=element_text(size=20),
            axis.text.x=element_text(size=20),
            axis.text.y=element_text(size=20))+
        ggtitle(title)
  return(g.bias.v)
}

################
# All together #
################
grid.arrange(
  bias.gr(v="acti_so3x_sed", title="GT3X-Soj3x"),
  bias.gr(v="acti_so1x_sed", title="GT3X-Soj1x"),
  bias.gr(v="acti_incl_1s_sed", title="GT3X-Incli-1s"),
  bias.gr(v="acti_10s_sed", title="GT3X-8cnts<10s"),
  bias.gr(v="acti_incl_10s_sed", title="GT3X-Incli-10s"),
  bias.gr(v="acti_60s_sed50", title="GT3X-<50cpm"),
  bias.gr(v="acti_60s_sed", title="GT3X-<100cpm"),
  bias.gr(v="acti_60s_sed150", title="GT3X-<150cpm"),
  bias.gr(v="acti_incl_60s_sed", title="GT3X-Incli-60s"),
  bias.gr(v="activpal", title="activPal"),
  bias.gr(v="armband", title="Armband"),
  ncol=3)
```

CHAPTER IV

OVERALL CONCLUSION

Sedentary behavior (SB) which is defined as any purposefully engaged activities that are predominated by prolonged sitting or a reclining position with low energy expenditure of < 1.5 METs (Owen, Healy, Matthews, & Dunstan, 2010) is ubiquitous in modern society. As a distinct health risk behavior from physically inactive (Pate, O'Neill, & Lobelo, 2008), a growing body of literature has demonstrated that the increased time spent in SB is deleteriously associated with cardio-metabolic biomarkers, obesity, type II diabetes, and chronic disease related mortality (Bankoski et al., 2011; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Katzmarzyk & Lee, 2012; Koster et al., 2012; van der Ploeg, Chey, Korda, Banks, & Bauman, 2012; Wijndaele et al., 2011). Given the overwhelming awareness of the role of SB in public health, it is crucial of importance to better characterize SB using a valid and accurate assessment tool.

The overarching theme of this dissertation was to extend our knowledge on measurement issues in SB particularly focusing on the different types of objective monitoring devices. The first study entitled "*Extracting the objectively measured sedentary behavior from accelerometer data: Measurement considerations for surveillance and research applications*" examined the Actigraph accelerometer (model 7164; ActiGraph LLC, Pensacola, FL) data from the National Health Nutrition Examination Survey (NHANES) 2003-2005. The NHANES is a cross-sectional survey using a national representative sample of the US civilian non-institutionalized population. It has been extensively used to describe the prevalence of SB and to establish the evidence of dose-response relationships of objectively measured SB with a variety of health outcomes (Bankoski et al., 2011; Healy et al., 2011; Matthews et al., 2008). Specifically, the use of the threshold of <100 counts per minute (cpm) from vertical axis activity counts has been largely applied to describe SB from the NHANES accelerometer data; however, our main focus was not placed on the validity of activity count threshold to defined SB but rather on how to operationalize SB after accounting for the duration when converting accelerometer data to the time spent in SB. A major context of SB involves the prolonged sitting while typical approach (e.g., counting every single minute with activity counts less than the threshold of SB) does not account for the duration that may represent the aspect of *prolonged*. Our analytical approach to address this concern was unique and we examined the dose-response relationship of sedentary time with a set of health outcomes including the metabolic risk factors after accounting for different sedentary bout durations. The findings from this study indicated that the sedentary time with relatively shorter bout (i.e., < 10 minutes) was in general positively associated with health outcomes while the deleterious association was found in the sedentary time with relatively longer bout. The possible discussion of counterintuitive results pertaining to the short bout of sedentary time was related to 1) the measurement limitation of Actigraph model 7164 to distinguish the sedentary from the light-intensity physical activity (e.g., standing still); and 2) whether the short bout of sedentary time should necessarily be extracted for total sedentary time as they are harmful as the longer bout of sedentary time while the conceptual definition of SB may involve the substantially prolonged period.

Another important finding from the first study is related to the measurement issues in the sedentary breaks, which is conceptually defined as the interruptions in sedentary time. The absolute number of sedentary breaks by counting the transition points from sedentary to active phase from the accelerometer data has widely been used and previous reports indicated that increased number of sedentary breaks is favorably associated with health outcomes. Our analysis indicated that, however, operationalizing sedentary breaks in the current way cannot be considered as sedentary breaks as what it has been defined at the conceptual level. The absolute number of sedentary breaks is rather the incomplete measure of the pattern of sedentary bout that does not account for the duration of accumulated sedentary time. We concluded that the sedentary breaks should be distinguished from the pattern of sedentary time accumulation when operationalizing the sedentary breaks from the accelerometer data. One of the strategies we proposed in this study was to identify the 'sedentary behavior bout (SB-bout)' that may include the structured SB and possible breaks within the bout.

The second study entitled "*Validation of objective monitoring devices for the assessment of sedentary behavior in a free-living environment*" examined the validity of three accelerometers [Actigraph GT3X, activPal (Physical Activity Technologies, Glasgow, Scotland), and SenseWear™ Armband (Model MF-SW; Body Media, Pittsburgh, PA, USA)] in a free-living environment compared with a proxy of direct observation using an Autographer (Oxford Metrics Group, plc., Oxford, UK) automated wearable camera. Different approaches proposed from a body of literature for the GT3X accelerometer which include the thresholds, inbuilt inclinometer function, and the Sojourn method, a hybrid machine learning model that combines the artificial neural network with hand-built decision tree analysis were applied. The findings from this study indicated that activPal performed the best with high accuracy and precision estimates for total sedentary time compared to other accelerometer measures. Sojourn method significantly improved the performance of GT3X accelerometer in identifying SB compared to the threshold-based and inclinometer-based GT3X measures; however, there is still relatively large portion of misclassification compared to activPal. Furthermore, the misclassification of true non-sedentary due to the functional incapability of GT3X accelerometer can possibly be minimized when the measurement focus is placed on the structured SB by restricting the sedentary bout. Specifically, a combination of the threshold of <150 cpm with <900 second restriction on sedentary bout showed the improved performance of GT3X measure by minimizing the misclassification ratio. We also developed a new algorithm that can be used for identifying the SB-bout from the accelerometer data; however, the performance of the new algorithm was significantly influenced by the actual validity of each accelerometer measure to detect the postural information. The estimate of sedentary breaks obtained within the SB-bout was the most accurate when new algorithm is applied to activPal data.

In conclusion, the studies contained in this dissertation are the results of continuous effort to improve the measurement practice of objectively measured SB. We do not believe that this project is the first to address the measurement issues in monitoring devices for the assessment of SB. However, our unique analytical approaches by focusing on the sedentary bout and SB-bout would be a useful resource when refining data processing for accelerometer data. Future research recommendations include 1) conceptualizing the structured SB; 2) examining the physiological response across different sedentary bouts; 3) improving the Sojourn method and Sensewear Armband algorithm by incorporating well trained data with a large sample size with varying patterns of SB in a free-living setting; and 4) exploring and clarifying the sedentary breaks separated from the patterns of sedentary time accumulation.

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