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Convergent Validity and Test Re-Test Reliability of Two Accelerometers for Measuring Physical Activity and Sedentary Behaviour in a Healthy Population of Older Women

by

Ted Pfister

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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Abstract

A central aspect of physical activity (PA) and sedentary behavior (SB) research is accurate assessment in the context of disease outcomes. The primary objectives were to evaluate the convergent validity and test-retest reliability of the ActiGraph® GT3X+ (AG) and ActivPAL3® (AP) accelerometers. Participants were from the Breast Cancer and Exercise Trial in Alberta (n=225) and wore both monitors concurrently during waking hours for seven days. When comparing AG Vector Magnitude (VM) and Vertical axis (VT) with AP, all measures of PA were statistically significantly different with the exception of moderate activity between AG (VM) and AP (p=0.15). No statistically significant difference occurred between AP and AG (VM) or (VT) for time in SB with p=0.48 and p=0.27, respectively. Intraclass correlation coefficients (ICC) ranged from 0.66 to 0.93 for moderate and sedentary time by AG (VT), respectively. Despite small mean differences at the group level, limits of agreement suggest these devices cannot be used interchangeably.

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DEDICATION

To my family and partner Tacita

and special dedication to my mom, Chris

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List of Terms and Abbreviations

AFPRN	Alberta Family Physicians Research Practice Network
ANN	Artificial Neural Network
BAR	Bouchard Activity Record
BETA Trial	Breast Cancer and Exercise Trial in Alberta
BMI	Body Mass Index
CI	Confidence Interval
Concurrent Validity	Concurrent validity is demonstrated when a test correlates well with a measure that has previously been validated
Convergent Validity	Degree in which two measures that are theoretically related are in fact related
CT	Computed Tomography
DO	Direct Observation
DXA	Dual x-ray absorptiometry
ICC	Intra-class correlation coefficient
Inter-device reliability	Reliability estimated between recordings of two devices
Intra-device reliability	Reliability estimated from two recordings of the same device
MET	Metabolic Equivalent
SD	Standard Deviation
SHBG	Sex Hormone Binding Globulin
VM	Vector Magnitude
VT	Vertical Axis

Chapter One: **INTRODUCTION**

1.1 Rationale

At present, methods for quantifying physical activity behaviour in epidemiologic studies can involve subjective data collection methods such as self-reported questionnaires or direct observations. These methods are used to obtain an estimate of either current or past activity patterns. An important aspect of physical activity research involves quantifying these behaviours more accurately given some of the recognized limitations of self-reported behaviour data (1). This need stems from the importance of improving the internal and external validity of data collected on physical activity and health outcomes. Threats to validity in subjective measures include reporting errors because of difficulty in estimating quantities of physical activity, social desirability bias and recall errors, among others. By objectively measuring physical activity, several of these biases and threats to validity can be overcome and a more accurate assessment of the association between physical activity and health outcomes can be achieved.

A new area of research in physical activity and disease outcomes is the role of sedentary behaviour, independent from physical inactivity in disease etiology. Sedentary behaviour is defined as those activities or behaviours performed while awake that do not increase energy expenditure substantially above a resting level and are typically classified as being in a seated or lying position with a metabolic equivalent value (MET) of 1 to 1.5 with a MET value of 1 corresponding to the resting metabolic rate (1-3). MET values are typically grouped into categories of <3, 3-6 and 6+ METs corresponding to light, moderate and vigorous activity,

respectively (2). Sedentary behaviour has been associated with several chronic and metabolic diseases including cancer, diabetes and cardiovascular disease (4).

The emergence of accelerometry has enabled researchers to quantify both physical activity and sedentary behaviour and its many parameters objectively. The appropriate choice of accelerometer for epidemiologic studies that seek to objectively measure physical activity and sedentary behaviour is dependent on several factors, the most important being the validity and reliability of the estimates obtained. To date, most research on accelerometers has focused on the evaluation of single devices in small convenience samples (5-7). With many competing accelerometers available for use, researchers are left to determine which accelerometer is best suited for estimation of physical activity and sedentary behaviour for the population under study.

The motivation for this study was to provide empirical evidence on the convergent validity, the degree in which two measures that are theoretically related are in fact related and test re-test reliability, measuring the consistency of measures from one time to another, of two leading accelerometry methods that are currently in use: the ActiGarph® GT3X Plus and the activPAL3®. By comparing estimates of physical activity and sedentary behaviour from both devices worn concurrently in a large sample of post-menopausal women, researchers will be provided with information on how well these devices agree and improve the decision making process regarding which device or combination of devices is most appropriate for use in large scale epidemiologic studies.

1.2 Aims and objectives

The aim of this cross-sectional study was to assess the convergent validity and test-retest reliability of the ActiGraph® GT3X Plus and ActivPAL3® accelerometers and to make recommendations for the most appropriate device to use in studies that wish to objectively measure physical activity and sedentary behaviour. The specific primary study objectives are:

1) To compare these accelerometers with respect to estimates of physical activity and sedentary behaviour ;
2) To assess the test-retest reliability of each activity monitor.
3) To compare estimates of physical activity and sedentary behaviour determined by diary log non-wear removal with automatic wear-time estimation methods

Chapter Two: **LITERATURE REVIEW**

2.1 Physical activity and health outcomes

Understanding the role of physical activity, defined as any bodily movement produced by skeletal muscles that results in energy expenditure, in disease etiology is being recognized as increasingly important because of the accumulating evidence regarding the association between physical activity and health (8-12). Physical inactivity is a modifiable lifestyle risk factor for a wide variety of health-related problems as evidence has shown deleterious associations between physical inactivity and chronic disease (cardiovascular disease, diabetes mellitus, cancer, obesity, hypertension, bone and joint disease as well as depression) and pre-mature death (10, 13-16). Studies have demonstrated reductions in the risk of death by up to 20-35% for both men and women who were physically active (9, 17). Furthermore, observational epidemiologic studies provide evidence that regular physical activity is associated with reduced risk of all-cause mortality and cardiovascular disease in men and women and that a dose-response relation exists with individuals in the highest levels of physical activity having the lowest risk of death with reductions in risk of 20-35% compared to those in the lowest category of physical activity (18). Evidence from a prospective study of US male physicians demonstrated that those who reported weekly physical activity of moderate intensity had a reduced risk of type 2 diabetes by approximately 36% compared to those who engaged in physical activity less than once per week (11). Epidemiologic evidence demonstrates a reduction in the incidence of cancer with physical activity, including average risk reductions of 40-50% for colon, 30-40% for breast, endometrium and lung cancer, 10-30% for prostate and testis and finally 20-30% for ovarian cancer (12, 19).

Physical activity is important in preventing loss of bone mineral density, reducing risk of fracture and preventing osteoporosis (18). These benefits to bone and joint health with routine physical activity are particularly important to post-menopausal women (18).

Currently, the Canadian Society for Exercise Physiology (CSEP) recommends that adults between the ages of 18-64 years of age accumulate at least 150 minutes per week of moderate-to-vigorous (MPVA) activity per week, in bouts of 10 minutes or more (20). The United States Surgeon General Report on Physical Activity and Health states that individuals should achieve a moderate amount of physical activity, described as using approximately 150 calories per day or 1000 calories per week in order to obtain health benefits (16). The World Cancer Research Fund (WCRF) and American Institute for Cancer Research (AICR) second expert report indicates that for cancer prevention, individuals should be active for 30 minutes per day (21). Specifically, the report states that 30 minutes of moderate activity, described as any activity that increases heart rate and makes one breath more deeply, should be obtained with maximum health benefits coming from 60 minutes of moderate activity per day or 30 minutes of more vigorous activity (21). Reports from Statistics Canada indicate that only 15% of Canadian adults are currently meeting these recommended weekly physical activity guidelines. Similarly, the Unites States Surgeon General Report on Physical Activity and Health indicates that more than 60 percent of adults are not meeting regular physical activity recommendations with 25 %not being active at all (16). This high prevalence of inactivity is of particular public health concern since evidence suggests that even if individuals meet recommended physical activity guidelines they are still spending the majority of the waking day sedentary (22).

2.2 Sedentary behavior and health outcomes

Sedentary behavior is defined by posture (seated or lying position) and by low metabolic equivalents (METs) (23). A MET is a multiple of the resting basal metabolic rate, with sedentary behavior expenditure typically expending 1.0 to 1.5 METs (2). Sedentary behaviour, independent of physical activity, has been shown to be adversely associated with health outcomes of type 2 diabetes, premature mortality and cardio-metabolic risk biomarkers (23). In relation to cardio-metabolic health, evidence from the US National Health Nutrition Examination Survey (NHANES), demonstrates that adults spend 51-68% of the waking day in sedentary behaviour (24). Compared to other physical activity intensities, adults spend approximately 5% of the waking day in moderate to vigorous (MVPA) activities and the remainder of the day in light intensity activity (24). There is a close relation between light intensity activity and sedentary behaviour, since adults who spend more time in light intensity activity spend less time in sedentary behaviour (25). Evidence suggests that having a positive balance between time spent in light activity and sedentary behaviour is beneficial since light activity is inversely related to cardio-metabolic biomarkers (26). In relation to type 2 diabetes, accumulating evidence from cross-sectional and longitudinal studies demonstrates that the relation between sedentary behaviour and biomarkers of diabetes risk (27-29), abnormal glucose tolerance (30), two-hour plasma glucose (31) as well as diabetes as a health outcome (32-34). Accumulating evidence demonstrates a relation between too much sitting and other sedentary behaviors with premature mortality (35, 36), including all-cause mortality and CVD-related mortality in men and women (36). Strikingly, new evidence shows that leisure-time physical activity does not mitigate the effects of prolonged sitting time and that individuals with more than seven hours of MVPA per

day but who also had more than seven hours of sitting time demonstrated a 50% increase in the risk of all-cause mortality and twice the risk of CVD-related mortality compared to participants with the same amount of MVPA but with less than one hour sitting time per day (37). Results from the Australian Diabetes, Obesity and Lifestyle Study (AusDiab) show that individuals with continuous prolonged sitting time had a poorer metabolic profile compared to those with breaks or interruptions in sitting time (38). Similar results were found in NHANES with participants who had frequent breaks in sitting time showing more favorable associations with waist circumference and C-reactive protein compared to those with prolonged unbroken sitting time (25).

At present, given the changes to technology and increased mechanization, current occupational settings and types of travel actually promote increased time in sedentary behaviour and less physical activity (39). With the evidence of sedentary behaviour as an independent risk factor on various health outcomes, it is of particular public health concern since adults and particularly youth are becoming more sedentary (40). To date, no formal recommended guidelines regarding suitable reductions of time spent in sedentary behaviour have been developed. The United Kingdom's Start Active Stay Active document and the American College of Sports Medicine's position stand provide broad and general recommendations regarding sedentary behaviour which includes statements regarding reducing leisure television time and reducing prolonged sitting time (41, 42). Stronger evidence from experimental and intervention studies are needed that examine the impact of sedentary behaviour on health outcomes as well as interventions to decrease the amount of time sitting. This evidence will provide the necessary basis for developing public health guidelines regarding the amount of time that should be spent

sitting and how many interruptions in sitting time are necessary for improved health outcomes. These guidelines would be distinct from those being developed for physical activity. Public health strategies to reduce time spent sedentary could include targeting office based workers who are currently the largest occupational group and are highly sedentary (23). Strategies to reduce sitting time for these populations may include standing every 30 minutes and standing during meetings or phone calls (23). With the lack of experimental and interventions studies, guidelines for sedentary behaviour will remain vague.

2.3 Objective and subjective measures of physical activity and sedentary behavior

The accurate assessment of exposure variables under study in epidemiologic research is paramount to reducing measurement bias and improving the internal validity of research studies (43). The accurate measurement of complex behaviours of physical activity and sedentary behaviour is particularly challenging in epidemiologic research. As such, multiple methods of subjective and objective measurement techniques have been developed and used in epidemiology to estimate physical activity and sedentary behaviour. The most commonly used method of assessing physical activity and sedentary behaviour in epidemiologic studies has been the use of subjective questionnaire methods (43). Questionnaire or survey methods can be classified into four types and include diary surveys, recall surveys, quantitative history surveys and general surveys (44). Diary surveys can be characterized as being self-administered with a short reporting time-frame, usually less than 24 hours (44). These diaries can be accurate using a small timeframe, however, they may suffer from potential issues of cost and acceptability since participants may not wish to record every activity throughout a day and may even alter physical

activity patterns for ease of completion (44). Recall surveys can elicit information about physical activity and sedentary behaviour over the past 1-7 days using telephone interviews or mailed questionnaires as examples. An example of using diary log information to elicit information about physical activity over a short time frame is the Bouchard activity record (BAR). The BAR measures activity over a three day period in 15 minute bouts (45). Quantitative history procedures, such as recall questionnaires, involve inquiry about physical activity or sedentary behaviour over longer periods, ranging from one month to lifetime assessments. Quantitative surveys, such as the Past Year Total Physical Activity Questionnaire, that has previously been validated and tested for reliability (46), may be used in various populations and is self-administered and yields more detail on physical activity patterns. An example of an interview-administered survey is the Lifetime Total Physical Activity Questionnaire. This questionnaire has been shown to be reliable and captures data on frequency, intensity, duration and type of activity including household, occupational and leisure activity (47). In general, all questionnaire methods are prone to measurement error from recall errors, misinterpretation and social desirability bias. These errors in measurement can lead to systematic bias that can be differential or non-differential. Differential misclassification bias can occur if those participants with the measured outcome, for example cancer, were incorrectly classified with regards to amount or patterns of physical activity compared to those without cancer, resulting in over- or under-estimation of the true magnitude of the measure of association. Non-differential misclassification could occur if measurement errors with respect to the exposure status are independent of the outcome, with the measure of association being attenuated and approaching a null value.

Objective approaches for estimating physical activity and sedentary behaviour exist and include physiological measurements such as maximal oxygen uptake, doubly labeled water and direct observation (DO) (44). Research suggests the correlation between reported physical activity and measures of maximal oxygen uptake or physical work are modest in large population-based studies which is likely because cardio-respiratory endurance is partly attributable to genetic predisposition and therefore may be a poor indicator of physical activity (44). The doubly labeled water technique involves study participants ingesting water containing isotopically labeled oxygen and hydrogen atoms (44). Accurate estimates of energy expenditure can then be obtained by measuring the proportion of unmetabolized water and water that has entered the energy cycle. This technique is promising as it allows for free-living estimation of physical activity and is of little burden on the participant (44). However, for use in large scale epidemiologic studies, this technique would be very expensive. In addition, it provides no information on behavior or patterns of physical activity. Methods of DO, which typically consist of watching participant's patterns and types of physical activity and sedentary behaviour or using video cameras to record participants, are useful for small sample validation studies (44). The use of DO in large sample epidemiologic studies would be infeasible. There also exists a potential bias using DO since the observers may influence normal patterns of physical activity and sedentary behaviour. With these objective methods of physical activity and sedentary behaviour, it is clear that a methodological gap exists between accuracy and feasibility when attempting to estimate these behaviors in large samples.

The gap between accuracy and feasibility of estimating physical activity and sedentary behaviour using objective measures has become smaller with the use of wearable devices such as

pedometers and accelerometers (43). These devices have gained popularity for use in small and population-based studies since they have been shown to reduce measurement error resulting in more accurate measures of association (43). Pedometers were solely designed to assess walking behavior; however, with technological advances in accelerometry, information on the frequency, intensity and duration of physical activity or sedentary behaviour can be collected in a feasible way. Accelerometers measure the acceleration of objects along reference axes (5). Accelerometers can be used to detect velocity and displacement by integrating acceleration data with respect to time (5). Accelerometers can respond to gravity and provide tilt-sensing with respect to reference planes known as inclination data (5). These inclination data can then provide information on posture (5). Increases in technology since the 1950s has resulted in reduced costs of accelerometers and enhanced sensor performance (5). Commercially available accelerometers that have been used and compared in various studies include the CT1 and CT3 (StayHealthy Inc.), the AMP 331 (Dynastream Innovations Inc.), the GT3X and GT1M (ActiGraph® LLC.) and the activPAL (PAL Technologies Ltd.) (5). Relatively new models from ActiGraph® and PAL Technologies, the ActiGraph® GT3X+ and the activPAL3®, have similar movement and inclination technology that has not been compared previously. The appropriate choice of accelerometer for physical activity and health studies is dependent on several factors, the most important being the validity and reliability of the estimates of physical activity and sedentary behaviour of these devices as well as the ease of use and administration, the characteristics of the study population, the size of the study sample and the infrastructure and resources available for the processing of the data and analysis from these device.

2.4 ActiGraph® GT3X+

The ActiGraph® GT3X Plus uses a tri-axial accelerometer, collecting information on motion in three different planes including vertical, medio-lateral and anterior-posterior directions. These data are then presented in counts indicating physical activity intensity. Common cut-points have been established for two methods of measurement using this device. The vertical axis (VT) method is the most commonly used in previous literature with various models of the ActiGraph® accelerometer, including the GT1M and GT3X (48). The ActiGraph® VT detects movement in the vertical or y-axis only and includes count cut-points for each minute of recording (CPM) for sedentary (0-100 CPM), lifestyle (101-760 CPM), light-intensity (761-1951 CPM), moderate (1952-5724 CPM), vigorous (5725-9498 CPM) and very vigorous (9499+ CPM) activities (48).

Another method to evaluate physical activity intensity has been developed, known as Vector Magnitude (VM), which incorporates all three axes of movement (49). The ActiGraph® VM count cut-points take into consideration movement detected in all three planes of motion (x, y and z axes) and includes light activity (0-2690 CPM – sedentary behaviour), moderate (2691-6166 CPM), vigorous (6167 – 9642 CPM) and very vigorous (9643+ CPM) activities (49). Count cut-points have not been defined to estimate sedentary behaviour using VM, however, the ActiGraph® GT3X+ incorporates an inclinometer to detect body postures of sitting, lying and standing in order to estimate time in sedentary behaviour. Therefore, the sum of time spent in seated or lying positions detected via inclinometer is used to estimate sedentary behaviour. With no count cut-point to define sedentary behaviour, the estimation of light activity using VM starts

with zero counts by definition, however, to estimate light activity accurately, sedentary behaviour determined by the inclinometer is subtracted from light activity (0-2690 CPM).

2.5 ActivPAL3®

The activPAL3® is also capable of recording acceleration data in three axes. Previously, the activPAL® device was a uni-axial device (similar to older models of the ActiGraph®) monitor which was the most commonly used activPAL® from previous literature. Results from this device can be provided as summary data with information on time spent in sedentary behaviour, standing (upright), stepping activity, step count and cadence. To estimate time in various physical activity intensities, researchers can use the stepping rate to estimate energy expenditure in METs. Thus, physical activity can be categorized based on these MET values (2). Physical activity categories for the activPAL3® include light (moderate + vigorous – sedentary behaviour), moderate (3.0 -5.9 METs), vigorous (6+ METs) and MVPA (moderate + vigorous).

Sedentary behaviour is detected via a built-in inclinometer that has been previously validated (7, 50-52). The inclinometer detects postures of sitting, standing and lying with sedentary behaviour being the aggregate time in sitting and lying positions (23) . By estimating moderate and vigorous activity, sedentary behaviour can then be subtracted from this time to accurately estimate light intensity activity.

2.6 ActiGraph® vs. activPAL®

All potentially relevant articles were identified by searching Medline between 1980-present, EMBASE (ExcerptaMedica Database) between 1980-present and SPORTDiscus

between 1985-present. Relevant data were extracted and placed into summary tables (Tables 1-3). Few studies have directly compared the performance, reliability and validity of ActiGraph® and activPAL® monitors (51-56). In the majority of studies that have examined and compared both devices, there is an emphasis on the evaluation of sedentary behavior. A study by Kozey-Keadle and colleagues (2011) observed 20 inactive office workers for two six-hour periods, the first in a free-living condition and in second in an intervention condition designed to reduce sitting time (57). This study aimed to assess the validity of the ActiGraph® GT3X and activPAL® to estimate sedentary behaviour. These investigators found that, on average, the activPAL® and AG100 CPM underestimated sitting time compared to direct observation (DO) by 2.8% and 4.9%, respectively (56). Kozey-Keadle et al (2011) determined that only the activPAL® monitor was sensitive to reductions in sitting time and that the AG150 CPM demonstrated the least amount of bias (1.8%) among other sedentary behaviour cut-points for the ActiGraph® device, ranging from AG50 CPM to AG250 CPM (56) .

Another study by Ridgers and colleagues (2012) used a sample of 48 children 8-12 years old to assess sedentary behaviour during class-time, break time and school hours using the ActiGraph® GT1M and the activPAL® (58). Similar to Kozey-Keadle et al. (2011), this study tested multiple ActiGraph® cut-points to assess sedentary behaviour, ranging from AG50 CPM to AG850 CPM. Compared to the activPAL® device, this study found that the AG100 CPM demonstrated the smallest mean difference between monitors (-5.2 minutes) during school hours (58). Ridgers and colleagues (2012) also performed a Receiver Operator Characteristic (ROC) analysis to determine which ActiGraph® cut-point was the most accurate in assessing sedentary

behaviour and found that a cut-point of 96 CPM, used to estimate sitting time, had an acceptable sensitivity (71.7%) and specificity (67.8%) (58).

Another study by Ryde and colleagues (2012) aimed to assess sedentary behaviour using the ActiGraph® GT3X+, the activPAL®, and a sitting pad (SP) compared to DO using a video camera (52). This study tested 13 adults with a mean age of 30 years during two testing protocols, one a free-living condition and the other with prescribed sitting and standing periods (52). These investigators found that the SP had the smallest mean difference compared to DO for total time in sitting (minutes) for both the prescribed and free-living conditions at 0.30 minutes and 0.16 minutes, respectively (52). Compared to DO, the ActiGraph® device had the largest mean difference in both protocols with -1.49 minutes and -14.05 minutes, respectively (52). Ryde and colleagues (2012) used Intra-class correlation coefficients (ICCs) to estimate the agreement of the ActiGraph®, activPAL® and SP compare to DO (52). The estimated agreement was high for both SP and activPAL® for total time sitting with ICCs of 0.999 and 0.990, respectively (52). The ActiGraph® GT3X+ demonstrated poor agreement compared to DO with an estimated ICC of 0.257 for total time spent sitting (52).

A similar study design by Lyden and colleagues (2012) aimed to assess sedentary behaviour using the ActiGraph® GT3X and activPAL® device compared to DO on 13 adult subjects during two 10 hour testing protocols, one a free-living condition and the other participants were asked to break up their sitting time (51). This study found that the activPAL® device was not statistically significantly different from DO for total time in sedentary behaviour, number of breaks in sedentary behaviour and break rate (51). Compared to DO, the activPAL® had an estimated bias (% bias (95% CI) of 1.6 (-0.1 to 3.4) for total time in sedentary behaviour

during the free-living condition and -0.1 (-0.9 to 1.1) for total time in sedentary behaviour during the treatment condition. In general, the AG100 CPM and AG150 CPM were not accurate in estimating breaks, break rate or total time in sedentary behaviour compared to DO (51).

Few studies have used the ActiGraph® and activPAL® device to measure both physical activity and sedentary behaviour. To date, seven studies have made this direct comparison (51-56, 58). A study by Hart and colleagues (2011) aimed to assess physical activity categories of walking, standing and MVPA as well sedentary behaviour using the ActiGraph® GT1M, activPAL® and the Bouchard Activity Record (BAR) (54). Using 32 adult participants, the study found a significant difference between activPAL® and ActiGraph® for total time in sedentary behaviour ($p<0.001$) (54). Significant differences were also found between ActiGraph® and activPAL®, and ActiGraph® and BAR for time in walking. Bland-Altman plots were used to assess agreement between methods and showed no systematic bias for all instruments in all behaviour categories, except for activPAL® and BAR for standing, activPAL® and ActiGraph® for walking, as well as for ActiGraph® and BAR for walking (54).

Dowd and colleagues (2012) used the ActiGraph® GT3X and activPAL® to estimate physical activity and sedentary behaviour compared to DO in a sample of 30 adolescent females between the ages of 15 and 18 years (53). This study estimated percent agreement defined as the agreement between all observed samples and activity monitoring samples ((number of observed samples which were correctly identified by activPAL® or ActiGraph® ·100)/total number of samples) (53). The percent agreement was high between activPAL® and DO for categories of sitting, standing and stepping at 100%, 98.1% and 99.2%, respectively. The overall estimated percent agreement for the ActiGraph® GT3X compared to DO was 66.7% (53).

Another study by Martin and colleagues (2011) assessed physical activity and sedentary behaviour using the ActiGraph® GT3X and the activPAL® in a sample of 23 pre-school aged children (55). Using paired t-tests, this study found a statistically significant difference between ActiGraph® and activPAL® for time in sedentary behaviour ($p<0.001$) (55). No statistical test was reported for time in physical activity. Bland-Altman plots were used to assess agreement between devices at the individual level and determined the agreement (% difference (95% limits of agreement) for time in sedentary behaviour was -4.5% (-14.0 to 5.4%) and concluded the two devices cannot be used interchangeably (55). Despite the poor estimated agreement, Martin and colleagues (2011) mentioned that, at the group-level, estimated times in sedentary behaviour and physical activity were similar.

Despite these studies incorporating the activPAL® device and some version of the ActiGraph®, very few studies have utilized or compared specifically the ActiGraph® GT3X+ and the activPAL3® . Only one study by Ryde and colleagues (2012) used the ActiGraph® GT3X+ and compared time in sedentary behaviour to the activPAL® using both devices inclinometer function, instead of the previously validated AG100 CPM (48). All of the studies comparing the ActiGraph® and activPAL® used uni-axial accelerometer data recorded from the vertical axis only (VT). Both the ActiGraph® GT3X+ and activPAL3® devices are tri-axial and no comparisons between these two methods have been made. Although most studies that have compared each device to the gold standard of direct observation to estimate the criterion validity, few studies have made head-to-head comparisons of each device in order to assess the concurrent validity at the group and individual level. Furthermore, research comparing the ActiGraph® and activPAL® has focused on small convenience samples. Therefore there is a gap in the

current literature with no assessment of the concurrent validity or reliability of the ActiGraph® GT3X+ and activPAL3® in a large and more heterogeneous study sample.

2.7 Reliability

2.7.1 *ActiGraph®*

Few studies have specifically examined the reliability of the ActiGraph® device. Two studies assessed the reliability of the ActiGraph® 7164 model (59, 60). McClain and colleagues (2007) used Intra-class correlation coefficients (ICC) to assess the inter-instrument reliability of the ActiGraph® 7164 on small sample of 10 adults in a free-living condition (61). The participants wore two devices over a 24-hour period and found high inter-instrument reliability across all physical activity categories and sedentary behaviour. Specifically, McClain and colleagues (2007) estimated the inter-instrument reliability (ICC) to be 0.98 for time in light and moderate activity while times in sedentary behaviour and MPVA were estimated to have a reliability of 0.99. Sirard and colleagues (2011) also estimated the inter-instrument reliability of the ActiGraph® 7164 using a sample of 143 adults from the Twin Cities Walking Study (59). This study estimated physical activity and sedentary behaviour using multiple automatic wear-time estimation and had participants wear the same ActiGraph® device for two seven day monitoring periods one to four weeks apart (59). Sirard and colleagues (2011) found high inter-instrument reliability across all physical activity categories and for all algorithms, with ICCs ranging from 0.70 to 0.90, noting that the ICCs increased when larger non-wear windows were used and was highest using a non-wear window of 60 minutes consecutive zero-count data with more than 10 hours wear-time per day (59). One study by Vanhelst and colleagues (2012)

assessed the inter-instrument reliability of the ActiGraph® GT1M using a coefficient of variation (CV)(62). Similar to the study by McClain and colleagues (2007), this study had 15 adults wear eight monitors for a 24 hour free-living period. Estimating physical activity and sedentary behaviour using VT cut-points, the CV varied from 7.1% to 15.5% for sedentary activity, 2.9% to 6.0% for light activity, 1.8% to 4.2% for moderate physical activity, and 1.2% to 4.8% for vigorous physical activity (62). A study by Santos-Lozano and colleagues (2012) assessed the reliability of the ActiGraph® GT3X, the only study to assess the reliability of the VM cut-points developed by Freedson et al (2011) (63). In this study, one adult male wore eight monitors in a laboratory setting and was instructed to perform tasks of resting, sit-to-stand transitions and walking on a treadmill at 4, 6, 8 and 10 km/h. This study estimated the inter-instrument reliability (ICCs) to be high for each individual axis of movement (ICC $\geq$0.925) and for VM (ICC $\geq$0.946) (63).

The majority of studies have assessed the inter-instrument reliability of the ActiGraph® device (Table 2). Despite the majority of studies assessing the reliability in free-living conditions for approximately 24-hours, only one study has assessed the intra-device reliability on two separate testing periods (59). One study used the ActiGraph® GT3X and assessed the reliability of the VM cut-points (63). No study has assessed the intra-device test-retest reliability of the ActiGraph® GT3X+ in a free-living condition, including sedentary behaviour detected by the devices inclinometer function.

2.7.2 ***activPAL®***

Four studies have assessed the inter-monitor or intra- monitor reliability of the activPAL® device (6, 7, 64, 65). Ryan and colleagues (2006) estimated the inter-device reliability of the activPAL® device using 20 healthy adults who each wore two devices (66). This study used a laboratory-based setting to assess reliability of the activPAL® step-count and cadence during two defined protocols with the first having participants walk at treadmill speeds of 0.90, 1.12, 1.33, 1.56, and 1.78 m/s and the second walking outdoors at self-selected speeds. Ryan and colleagues estimated the inter-device reliability (ICC) at 0.99 for both step count and cadence and concluded the activPAL® was a reliable measure of walking in healthy adults (66). A similar study by Grant and colleagues (2006) used a convenience sample of 10 healthy adults who wore three monitors during two laboratory-based protocols, one was a controlled condition in which participants were asked to walk, sit and stand for periods of two to nine minutes and the second was a protocol comprised of activities of daily living (ADL) in which participants performed six random tasks associated with daily activities (50). This study estimated the inter-device reliability (ICC) to 0.99 for sitting/lying, standing, walking while the inter-device reliability for walking in the ADL section (ICC) was 0.79. Two studies assessed the intra-device reliability using ICCs. One study by Dahlgren and colleagues (2010) sampled 24 adults wearing the same monitor on two separate occasions in a laboratory setting (67). Participants were asked to walk at self-selected pace, treadmill walk at 3 speeds (3.2 km/h, 4.5 km/h, 4.5km/h + incline), jog on the treadmill (8.0 km/h), cycle at 3 speeds (45, 60 and 70 RPM) and engage in stair walking. The estimated **i**ntra-device relative reliability (ICC) was high for treadmill walking at 3.2 km/h, 4.5 km/h, 4.5 km/h incline and jogging at 0.88, 0.94, 0.95 and 0.81, respectively.

Reliability estimates were low for cycling at 45, 60 and 75 rpm with ICCs of 0.27, 0.12 and 0.55, respectively. Another study by Hinckson and colleagues (2013) assessed the intra-device reliability in school aged children who wore the activPAL® for 24 hours per day for approximately 14 days (65). Reliability (ICC) was expressed as the change in the mean from week to week with time in sedentary behaviour, standing and stepping expressed as the percent of time per day on both weekdays and weekends. Hinckson and colleagues (2013) estimated the intra-device reliability (ICC) to range from 0.40 to 0.79 during the weekday and from 0.25 to 0.60 during weekends (65). For both weekdays and weekends, estimated reliability was low to moderate across all categories of sitting, standing and stepping (65).

The majority of studies assessing the reliability of the activPAL® device were laboratory-based, involving participants running and walking on treadmills at various pre-determined speeds (6, 7, 64) (Table 2). Only one study using children assessed reliability in a free-living condition for a period of approximately two weeks (65) (Table 2). Furthermore, the majority of studies have assessed the inter-monitor reliability on small convenient samples in a laboratory setting. Two studies assessed the intra-device reliability on two separate testing occasions and only one in a free-living condition. No study has assessed the intra-monitor test-retest reliability of the activPAL3® monitoring device in a free-living condition.

2.8 Estimation of wear-time

Few studies have aimed to develop and test automatic wear-time algorithms for accelerometer data worn over multiple days (68-71). In large scale epidemiologic studies, manual processing of accelerometer data is taxing, requiring manual non-wear removal with the

use of diary log information. The development of automatic processing methods can estimate wear-time, remove non-wear periods and estimate physical activity and sedentary behaviour in large samples relatively quickly and efficiently. A study by Masse and colleagues (2005), re-analyzed accelerometer data on 242 women from the Women on the Move (WOTM) study, a five year prospective study to validate physical activity questionnaires (68). This study analyzed data from the ActiGraph® 7164 model using four separate wear-time algorithms (Table 3). Masse and colleagues (2005) found that the more stringent the criteria placed on the algorithm the more likely it adversely affected physical activity variables (68). The study found that the second algorithm (Table 3) with the smallest window of zero-counts combined with only three days of valid data produced the lowest estimated wear-time, activity time, counts per minute and counts per day (68). Subsequently, the estimated time in MVPA from algorithm two, the most stringent algorithm, was significantly reduced compared to all other algorithms. Masse and colleagues (2005) also noted that if the algorithm allowed for one to two minutes of interruptions in the non-wear window, meaning count-data are present for a couple minutes in-between a larger zero-count window, estimated time in MVPA did not change significantly. However, if no interruptions were allowed, estimated time in MVPA significantly decreased. Work from Troiano and colleagues (2007), using NHANES accelerometer data from 2003-2004, has led to the most commonly used automatic wear-time algorithm (70). This algorithm (Table 3) estimated physical activity on a large sample of 4867 individuals ranging in age from youth (6-11 years) to senior (60+ years). Troiano and colleagues (2007) developed this algorithm to estimate wear-time and physical activity variables during the waking day and has demonstrated that study participants tend to over-estimate self-reported physical activity (70). More recently, a

study from Choi and colleagues (2011) aimed to create and improve the commonly used algorithm developed by Troiano et al (2005) (Table 3) (71). In this study, two separate algorithms (Table 3) were compared using a sample of 49 adults and 76 youth. Participants were monitored using the ActiGraph® GT1M for a strict 24 hour stay in room calorimeter as the gold standard. Compared with the true wearing status, improvements to the algorithm decreased non-wear time misclassification during both the waking day and 24 hour periods for both adults and youth (Wilcoxon rank-sum P values <0.001). Choi and colleagues (2011) noted that the previous algorithm developed by Troiano et al (2007) performed well during the waking day for youth and may perform better for people (such as youth) with a more active life style compared with people who have a relatively sedentary lifestyle (71). The new algorithm by Choi and colleagues (2011) (Table 3) may provide a more accurate estimation of time spent in physical activity and sedentary behaviour as misclassification of wear-time is reduced.

One study has assessed algorithm performance using VM cut-points from the ActiGraph® GT3X monitor (69). Choi and colleagues (2012) compared the same two algorithms from Troiano et al (2007) and Choi et al (2011) (Table 3) on a sample of 29 older adults aged 76-96 years. Participants wore two ActiGraph® models, the tri-axial GT3X worn on the wrist using VM cut-points and the uni-axial GT1M worn on the waist using VT cut-points. This study found that between algorithms, the probabilities of correct classification by the new algorithm (Choi et al, 2011) were significantly greater (Wilcoxon rank-sum $p<0.05$) than those by the older algorithm (Troiano et al, 2007) (69). This study also confirmed previous results from Choi and colleagues (2011), that the larger 90 minute zero-count window to classify non-wear reduced misclassification bias and is now applicable to older adults. Choi and colleagues (2012) also

observed that the VM counts were more sensitive in detecting movement and performed better than the VT cut-points (69). Choi et al (2012) concluded that the larger 90 minute non-wear window using VM cut-points improved the overall performance of these previous algorithms (69).

Despite these algorithms being previously validated and used in representative samples, it would be wise to test an algorithm with varying parameters, such as non-wear windows of 60 or 90 minutes to assess which best suits the population under investigation. These previous algorithms developed by Troiano et al (2007) and Choi et al (2011) provide a basis to employ automatic techniques to estimate wear and non-wear data from ActiGraph® accelerometers in large scale epidemiologic studies. No previous research has developed or validated an automatic wear-time algorithm for the activPAL® device.

Table 1: Summary of studies comparing the ActiGraph® and activPAL®.

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
Kozey-Keadle et al. (2010)	N=20 overweight (mean ±SD: body mass index = 33.7 ± 5.7 kg·m^2) inactive, office workers age 46.5 ± 10.7 yr	Cross-sectional	·SB only	activPAL and ActiGraph GT3X	AP and AG100 underestimated sitting time compared to DO by 2.8 and 4.9%, respectively Only AP detected reductions in sitting time AG150 CPM had smallest bias (1.8%) of AG cut-points	AP more precise and sensitive to reductions in sitting time Multiple AG cut-points to detect SB were used with AG150 being the most accurate Study used gold standard of direct observation
Hart et al. (2011)	N=32 participants 18–60 yr old, body mass index (BMI) <30 kg·m^2	Cross-sectional	·PA (walking, MVPA, standing) and SB ·PA and SB categories for AG from Freedson et al (1998).	activPAL, ActiGraph GT1M, Bouchard Activity Record (BAR)	Significant difference between AP and AG for total time in SB ($p<0.001$) No significant difference between AP and BAR Significant difference between AG and AP and AG and BAR for walking B-A plots show no systematic bias for all instruments in all behaviour	BAR shows high agreement with AP AP could not differentiate intensity of walking and did not have capability to detect MVPA in this study. Used very large epochs of 15 mins in order to compare with BAR. Data smoothing could occur

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
					categories, except for activPAL and BAR for standing, activPAL and ActiGraph for walking, as well as for ActiGraph and BAR for walking	(e.g. 15 min classified as SB despite brief periods of PA).
Martin et al. (2011)	N=23 pre-school children	Cross-sectional	PA and SB SB detected as <1100 CPM for AG	AG GT1M AG GT3X (vertical only) AP	Significant difference between AG and AP for time in SB ($p<0.001$) Nothing reported for PA Group means are very close between devices Bland-Altman plots show patterns and large limits and devices should not be used interchangeably at the individual level	Concurrently worn for 7 days (>10h/d) Used cut-points form 7164 model (very different from new models) Group values very similar, statistically significant Bland-Altman plots demonstrate individual problems with limits and patterns in data.
Ridgers et al. (2012)	N=48 children 8-12 years old.	Cross-sectional	SB only AG used range of counts to test SB (50, 100, 150, 200 up to 850 CPM)	AG GT1M AP	Smallest mean bias for AG100 for school hours only ROC analysis showed cut-point of 96 had best sensitivity/specificity (71.7% and 67.8%)	AG and AP data matched by date and time Used young children and tested many cut-points for SB Worn for 2 school days

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
						Bland-Altman plots show no pattern but large limits of agreement Mean differences for AG 100 compared to AP is small
Ryde et al. (2012)	N=13 9 women; mean age 30 ± 6.5 years)	Cross-sectional Compared camera (gold standard) to AG, AP and SP for sitting and transitions in sitting Two protocols, one described and other free living	SB only SB estimated via inclinometers from both devices	AG GT3X+ AP SP (sitting pad)	Smallest mean difference between camera and SP (sitting time 0.30 ± 0.21 minutes, transitions –0.46 ± 0.78) ICC's for free-living sitting and transitions for each method compared to camera, highest for SP (0.999) and AP (0.990) ICC for AG compared to camera was poor (0.257)	Small sample to test new sitting pad against AP and AG GT3X+ inclinometer used and performed poorly compared to gold standard camera * No comparisons made between AG and AP
Lyden et al. (2012)	N=13 Participants 20-60 years, healthy.	Cross-sectional	SB only: absolute number of breaks and	AG GT3X AP *AG tested with	AP was not significantly different from DO for total time in SB, # of breaks and break rate	Study used gold standard comparison of DO No statistically significant

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
	Two 10 hours sessions: baseline was free living and treatment asked to break up time in SB		break rate	LFE and without SB for AG estimated using AG100 and AG150	AP %bias for time in SB (95 CI) was 1.6 (-0.1 to 3.4) for baseline and -0.1 (-0.9 to 1.1) for treatment AG significantly different form DO for free-living and treatment conditions (LFE and no LFE) In general, AG100 and AG150 with LFE or no LFE was not accurate in estimating breaks or break rate or total time in SB compared to DO	difference for AP and DO for total time in SB, breaks and break rate for both baseline and treatment conditions No direct comparison between AG and AP GT3X+ was not used and no inclinometer measure AP valid tool to estimate SB in free-living environment
Dowd et al. (2012)	N=30 females 15-18 years	Cross-sectional	PA and SB Compared AP to SB in categories of sitting, standing and stepping AG100 for SB	AG GT3X AP	Agreement between AP and DO was 99.1% for all activities (100% sitting, 98.1% standing, 99.2% stepping) Agreement between AG and DO was 66.7% for all activities Strong positive relationship between count function of AG and AP ($r=0.96$ $p<0.01$) validity between devices	Adolescent female population Uniaxial AG and uniaxial AP AG100 has problems differentiating standing from sitting No inclinometer function in GT3X

Table 2: Summary of studies assessing reliability of the ActiGraph® and activPAL®

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
Grant et al (2006)	N=10 Healthy adults Convenience sample	Cross-sectional Laboratory based: two protocols, one on treadmill at self-selected speed and "ADL" protocol with 6 tasks.	3 devices used to measure inter-device reliability Activities of walking, standing and sitting captured on camera and compared to AP output	activPAL	The inter-observer reliability ICC was >0.97 for all individual postures (sitting, standing and walking) in both the controlled and ADL sections. Inter-device reliability ICC for sitting/lying, standing, walking and upright, in both sections, was .0.99. The inter-device reliability for walking in the ADL section (ICC) was 0.79.	AP reliable measure of posture and motion for everyday activities
Ryan et al (2006)	N=20 healthy adults	Cross-sectional Laboratory based to measure reliability of step number and cadence	Participants walked on a treadmill at five different speeds (0.90, 1.12, 1.33, 1.56, and 1.78 m/s) and outdoors at	activPAL	Inter-device reliability at all speeds, inter device reliability was excellent for the activPAL (ICC >0.99) for both step number and cadence.	activPAL reliable measure of walking in healthy adults

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
			three self-selected speeds (slow, normal, and fast).			
Dahlgren et al (2010)	N=24 adults, 19–28 years	Cross-sectional Treadmill activities on two occasions 1 week apart in laboratory setting	Assessed self-paced walking, treadmill walking at 3 speeds, treadmill jogging, cycling at 3 speeds and stair walking	activPAL	Intra-device relative reliability (ICCs) high for treadmill walking at 3.2 km/h, 4.5 km/h, 4.5 km/h incline at 0.88, 0.94, and 0.95. Low reliability cycling at 45, 60 and 75 rpm with ICCs of 0.27, 0.12, 0.55 Self-selected walk ICC of 0.69	ActivPAL had high or very high relative and absolute reliability for treadmill walking, and jogging activities at all speeds and stair walking, over time. Moderate reliability for self-paced floor walking and cycling at 75 rpm.
Hinckson et al (2012)	N=56 children age (mean±SD 10.2 ±0.9 years)	Cross-sectional Children wore monitors of 24 h/d for 14 days	Reliability (ICC) was expressed as change in the mean from week to week Assessed SB, standing and stepping on weekdays	activPAL	ICC values ranged from 0.40 to 0.79 during week days and 0.25–0.60 during weekends	The ActivPAL showed moderate to low week-to-week reliability for habitual activity and postural allocation under free living conditions in boys and girls.

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
McClain et al (2007)	N=10 participants (four males, six females; age = 30.1± 3.8 yr).	Cross-sectional 10 distinct pairs of monitors worn by participants for one 24 hour free-living period	Assessed inter-instrument reliability using ICCs on PA and SB using published cut-points (VT axis).	ActiGraph 7164	ICCs for light and moderate were 0.98 ICCs for SB, vigorous and MVPA were 0.99	High inter-instrument reliability across all PA categories and SB
Sirard et al (2011)	N=143 adults from Twin Cities walking study	Cross-sectional Participants wore same AG for two seven day monitoring periods 1-4 weeks apart	Assessed reliability of PA estimates using multiple wear-time algorithms	ActiGraph 7164	Reliability very good to excellent (ICC = 0.70–0.90) for almost all algorithms and there were no significant differences between physical activity measures at Time 1 and Time 2.	The ActiGraph was highly reliable in measuring activity over a 7-day period in natural settings but data were sensitive to the algorithms used to process them.
Vanhelst et al (2012)	N=15 adults, 7 women, 8 men. (mean (SD)) of (29.4 (3.8)) years	Cross-sectional Participants wore 8 monitors for 24 hour	Assessed coefficient of variation (CV) between monitors for all PA intensities	ActiGraph GT1M	The inter-instrument CV for the ActiGraph was 3% to 10.5% across all physical activity intensities The physical activity intensity was inversely	Reliability higher for MVPA activity More variation between devices for SB and light activity

Author (year)	Study sample (n)	Study design	PA and SB assessment	Devices	Results	Comments
		period in free-living condition	(cut-points from VT axis)		related to the inter-instrument CV. The CV varied from 7.1% to 15.5% for sedentary activity, 2.9% to 6.0% for light physical activity, 1.8% to 4.2% for moderate physical activity, and 1.2% to 4.8% for vigorous physical activity. The average CV was 3.3%.	
Santos-Lozano et al (2012)	N=1Adult male, 27 years of age	Cross-sectional Assessed reliability of 8 monitors during rest, walking and repeated sit-to-stand transition	Assessed inter-monitor reliability over range of PA in both individual axes and in VM	ActiGraph GT3X	The intra-class correlation coefficients were high for *X*, *Y* and *Z* axes (≥ 0.925) and for VM (≥ 0.946).	Good inter-instrument reliability across all planes of motion for GT3X device. VM doesn't necessarily provide any benefits to traditional vertical axis estimates

Table 3: Summary of studies assessing algorithms for data processing with the ActiGraph® device

Author (year)	Study sample (n)	Study design	Reduction Algorithm	Devices	Results
Masse et al (2005)	N= 242 women from the Women On The Move (WOTM) study, a 5 year prospective study to validate PA questionnaires	Cross-sectional Reanalyzed accelerometer data using 4 separate wear-time algorithms	Compared 4 separate algorithms with varying parameters including: 1) Non-wear widow: 60 min, 20min 2) Minimum wear time per day: 10 hours, 12hours, 60% waking day 3) Spurious data: >20,000 counts, 16,000 counts, >0 counts for 10 mins 4) # days to compute outcome variables: 3 days, 4 days, 7 days 5) Duration of interruptions: 1 min, 2min	ActiGraph 7164	Most stringent criteria (algorithm 2) effects outcomes, with MVPA in algorithm 2 at 17 min/day and MVPA in algorithms 1,3 and 4 at 22.8, 22.5 and 22.3, respectively Algorithm 2 with lowest wear-time, activity time, counts per minute and counts per day Time in MPVA did not change significantly with 1 to 2 min interruptions. Without 1-2 min interruptions, MVPA significantly decreased
Troiano et al (2008)	N= 4867 Data from 2003–2004 National Health and	Cross-sectional	1-min time intervals with consecutive zero counts for at least 60-min time window, allowing up to two consecutive intervals (min) with non-zero counts less than or equal to 100 counts; any	ActiGraph 7164	No comparisons of various algorithms, however, accelerometer derived estimates of PA lower than self-report

Author (year)	Study sample (n)	Study design	Reduction Algorithm	Devices	Results
	Nutritional Examination Survey (NHANES)		encounter of counts above 100 is considered wear.		
Choi et al (2011)	N=125 49 adults and 76 youth monitored for 24 hour period in room calorimeter	Cross-sectional	Compared two algorithms: 1) 1-min time intervals with consecutive zero counts for at least 60-min time window, allowing up to two consecutive intervals (min) with nonzero counts less than or equal to 100 counts; any encounter of counts above 100 is considered wear. (Troiano) 2) 1-min time intervals with consecutive zero counts for at least 90-min time window (window 1), allowing a short time intervals with nonzero counts lasting up to 2 min (allowance interval) if no counts are detected during both the 30 min (window 2) of upstream and downstream from that interval; any nonzero counts except the allowed short interval are considered as wearing	ActiGraph GT1M	Compared with the true wearing status, improvements to the algorithm decreased non-wear time misclassification during the waking and the 24-h periods for both adults and youth (Wilcoxon rank-sum P values < 0.001)

Author (year)	Study sample (n)	Study design	Reduction Algorithm	Devices	Results
Choi et al (2012)	N=29 adults Age: 76-96 years	Cross-sectional	Compared Choi and Troiano algorithms on tri-axial (VM) wrist-worn monitor and uni-axial waist worn monitor (VT)	ActiGraph GT3X ActiGraph GT1M	Comparison between 60- and 90-min windows. The performance of both algorithms using the 90-min window was better than that using the 60-min window for both wrist (VM and V) and waist (V) monitor data (Wilcoxon ranks sum $P < 0.05$). Comparison between VT and VM Counts: For both 60- and 90-min window time settings, the VM counts were more sensitive in detecting movement and hence performed better than the V counts (all P values <0.05). The bias of Choi's algorithm was smaller than Troiano for all comparisons ($P <0.05$)

Chapter Three: **METHODS**

3.1 Study design – BETA Trial

The data used in this secondary analysis originated from the Breast Cancer and Exercise Trial in Alberta (BETA Trial), a two-armed randomized controlled exercise intervention trial conducted in Calgary and Edmonton between 2010 and 2013 that examined the effects of 12 months of moderate (150 minutes/week) versus high (300 minutes/week) volume of aerobic exercise on various hormonal and biological mechanisms that are hypothesized to be operative in the association between physical activity and breast cancer risk. A brief discussion of the research objectives, sampling strategy and data collection procedures used in the BETA Trial are outlined below.

3.1.1 **Aims**

Specific objectives of the BETA Trial included comparing the effects of these exercise interventions on obesity levels (Body Mass Index (BMI), intra-abdominal fat, and subcutaneous fat) and markers of insulin resistance (insulin, glucose, leptin, adiponectin) in which there is strong or probable evidence of an association with breast cancer risk. Another objective was to compare the effects of the exercise intervention on sex hormone levels, including estrogen, estradiol, testosterone and sex hormone binding globulin (SHBG) in which there is moderate evidence of an association. The final objective was to compare the effects of the exercise intervention on inflammatory markers, including Interleukin-6, tumour necrosis factor-alpa and C-reactive protein all hypothesized to be associated with breast cancer risk. A secondary aim included evaluating the impact of the exercise intervention on psychosocial factors, including

quality of life, perceived stress, sleep quality and adherence to the intervention during the trial and maintenance 12 months afterwards.

3.1.2 **Sampling**

The BETA Trial study population consisted of postmenopausal English speaking women from Calgary and Edmonton, aged 50-74 years who were inactive at baseline. The eligibility criteria focused on identifying women in whom it may be possible to affect breast cancer risk. These criteria aimed to ensure participants were in an appropriate target group for breast cancer risk reduction which included the age range of 50-74 years, post-menopausal and no previous breast cancer diagnosis. Participants also had to be physically fit to undertake the exercise intervention and have no other outside factors to influence estrogen metabolism. Outside factors influencing estrogen metabolism included not being a current smoker, excessive drinker (no more than 14 drinks per week) and not planning on undertaking a weight loss program or weight loss medication. The study enrolled a total of 400 women and 200 were randomized to themoderate volume exercise group and thehigh volume group.

3.1.3 **Recruitment and eligibility**

Women who were potentially eligible for participation in the trial were identified and sent letters of invitation from Screen Test: The Alberta Breast Cancer Screening Program, and via media advertisements. Women in the Screen Test database who were between the ages of 50-74, lived in Edmonton or Calgary, and who had attended Screen Test within the last two years were sent a letter of invitation directly by Dr. Tim Terry, Chief Radiologist of Screen Test.

Posters and pamphlets were distributed primarily in family physicians' offices who were part of the Alberta Family Physicians Research Practice Network (AFPRN), a program of the Alberta College of Family Practitioners. The AFPRN sent packages to 2000 family physicians in Edmonton and Calgary asking if they would participate in facilitating recruitment to the trial by having BETA Trial posters and brochures in their respective offices. A media campaign was also initiated to increase awareness and interest in the BETA Trial.

After initial telephone screening of all women (n=8794), 2028 were deemed eligible and contacted to be assessed using the Participant Eligibility Questionnaire (PEQ). The PEQ excluded 988 participants. Ultimately, 863 participated in an information session, after which multiple tests were conducted to determine eligibility for the trial. The tests included: 1) a medical clearance from their family physician through the completion of a Physical Activity Readiness Medical Examination form (PARmed-X); 2) a fasting blood draw to screen those participants with underlying conditions that would prevent them from participation in the exercise intervention (e.g. diabetes, kidney or liver diseases); 3) a sub-maximal aerobic fitness test (modified Balke) to assess whether or not participants are too fit for the trial, indicated by a maximum oxygen update of 34.5 ml/kg/min (72). The fitness test was also used to determine the exercise prescription for the trial.

3.1.4 ***Data collection***

3.1.4.1 Adiposity

Standardized methods of anthropometric assessment weretaken by exercise trainers previously trained and included measures of height, weight, hip and waist circumferences. Body

fat was assessed using Computed Tomography (CT) and Dual Energy X-ray Absorptiometry (DXA) scans. The CT scanners are located at the Tom Baker Cancer Center (TBCC) in Calgary and the Cross Cancer Institute (CCI) in Edmonton. A CT scan at the level of the umbilicus measured intra-abdominal, subcutaneous fat and total-abdominal fat in order to derive a measure of central adiposity. The DXA scan was performed at the Human Performance Lab (HPL) at the University of Calgary and the Human Nutrition Research Centre at the University of Alberta. The DXA scan measured total percent body fat and its relative distribution throughout the body.

3.1.4.2 Blood samples

Blood samples were collected three times throughout the duration of the trial at baseline, 6 and 12 months. Blood draws were performed by Calgary Lab Services (CLS) in Calgary and by the CCI in Edmonton. All blood samples were stored in freezers at the Holy Cross Center in Calgary and at the U of A initially and then all stored in the Alberta Cancer Research Biorepository maintained by Alberta Health Services. The main planned assays are determining the levels of endogenous sex steroid hormones (estrone, estradiol SHBG); and insulin resistance (insulin, leptin, adiponectin and glucose), and inflammation (CRP, IL-6, TNF-α)

3.1.4.3 Accelerometry and SIT-Q

Participants wore accelerometers throughout the trial at baseline, 6 and 12 months and 12 months post-study completion. These devices provide an objective measurement of physical activity and sedentary behavior. Accelerometers measure acceleration or g-force units (m/sec^2) of body mass that is a result of muscular forces produced by the body (5). These acceleration

data are often expressed as counts, which is an arbitrary unit that can then be used to determine the frequency, intensity and duration of body motion. The BETA Trial used two kinds of accelerometers, the ActiGraph® GT3X Plus and the activPAL3®. Both of these devices measured acceleration in three planes of motion and this includes vertical, medio-lateral and anterior-posterior directions. Both devices aim to measure sedentary behavior accurately by assessing the intensity, duration and frequency of physical activity.

The SIT-Q is a questionnaire developed by Dr. Brigid Lynch that assessed the participants' past-year sitting behaviour. This questionnaire was administered at baseline, 12 months and 24 months to determine how sitting behaviour changed after being on a supervised exercise program, and then one year after completion of the trial.

3.1.4.4 Quality of life and determinates of adherence

It is hypothesized that the BETA Trial will provide mental benefits, including improved satisfaction with life and increased perception of control over the risk of breast cancer. Psychosocial and general health outcomes are being assessed using the self-administered RAND 36-item Health Survey (General Health Questionnaire), which assesses overall quality of life, as well as mental and physical health, functional status judgments, health perceptions and limitations in daily living at baseline, end-of-study and at 12 month follow-up points (73). The exercise training questionnaire measured adherence to exercise based on the Theory of Planned Behavior (74).

3.1.4.5 Covariates

Socio-demographic variables were measured using the Baseline Health Questionnaire that included information on the following variables: socio-demographic characteristics, menstrual and reproductive history, medical and health history, alcohol intake, past hormone replacement therapy, medication and vitamin/supplement use and smoking history (Appendix A.4.). Information on diet in the past year was assessed at baseline and 12 months using the Diet History Questionnaire from the National Cancer Institute (NCI) that had been previously adapted for use in Canada (75). Physical fitness was assessed using a sub-maximal VO_2 test, an objective measure of fitness that can be compared to self-reported physical activity.

3.2 Study design - Thesis project

This project is a cross-sectional analysis of accelerometer data collected at the 12 month time point in the BETA Trial. At that time point in the trial, the study participants wore both accelerometers simultaneously. The purpose of this study was to assess the convergent validity and test-retest reliability of the ActiGraph® GT3X+ and the activPAL3® and to assess the agreement of both devices for measuring physical activity and sedentary behaviour. The recording was seven days in duration and the monitors were worn for all "waking hours". The monitors were removed when they were sleeping and for any water-based activity. An activity monitor daily log was completed by each participant to record the time when the monitors were worn and what activities were done during "non-wear" time (Appendix A.3.). A reliability assessment was conducted on a small subset of 29 participants who wore both monitors for two seven day periods in close

succession. The focus of this project is to determine the convergent validity and test-retest reliability of the ActiGraph® GT3X+ and activPAL3® accelerometers and to explore wear-time algorithms for each device in order to automatically estimate physical activity and sedentary behaviour.

3.2.1 **Sample size**

All participants from the BETA Trial were eligible to be included in this thesis project. Using a two-tailed dependent t-test method, with a significance level of 0.05 and an approximate sample size of 300, it was estimated that this thesis project has sufficient power to detect a difference between these two instruments (Table 5) (76, 77). Estimates of power were consistently reported as above 80% for varying sample sizes ranging from 100 to 300 individuals with a range of standard deviations based on those previously reported (Tables 5 and Figure 1) (82). Valid accelerometer data were deemed to be a recording that were more than four days in duration with a minimum 10 hours recording time per day. It has been suggested that in order to obtain reliable estimates of physical activity at least three to four days of data should be collected with physical inactivity potentially requiring up to seven days of recording (24). Minimum daily wear-time is an important data reduction issue. The minimum wear-tie has to be high enough to eliminate days where the device was clearly not worn long enough to accuratelt depict physical activity and sedentary time but low enough to prevent too many files from being eliminated from analysis which would greatly reduce sample size and statistical power (83). A minimum wear-time of 10 hours per day appears to be common in the broader research community in order to accurately capture physical activity and sedentary time during the waking day (83). Invalid data were defined as those recordings with less than four days with a minimum 10 hours of recording

time or if a device was worn upside down (activPAL®). Furthermore, each device was matched by date of recording so those days that did not match were removed from the analysis. After removing those data deemed invalid, 225 participants were include for analysis comparing the ActiGraph® GT3X+ and the activPAL3®.

3.2.1.1 Reliability sampling

To measure the behavioural variation for each device, 29 participants were recruited by asking those individuals who were due for an accelerometer recording at the 12 or 6 month time point to complete the reliability protocol. If a participant refused, the next individual due for a recording was asked. The reliability estimate was achieved by having this subset of participants wear both monitors for two seven day monitoring periods approximately two weeks apart. During a time span of approximately four weeks, each participant wore both monitors during week one and the devices were returned and data downloaded during week two. The same monitors for each participant were then re-issued to wear for week three and subsequently returned and data downloaded on week four. In this sub-study, using a reliability sample of 29 individuals, it is estimated from previously reported ICCs on each device and previously reported methods of estimating ICCs and corresponding 95% confidence intervals that the test-retest reliability (ICC (95%CI)) for both devices can range anywhere from 0.81(.69 to 0.94) to 0.93 (0.88 to 0.98) (77).

3.3 Data collection

3.3.1 **ActiGraph® GT3X+**

The ActiGraph® GT3X+ device is manufactured by ActiGraph Corporation, Pensacola, Florida. The monitoring device is small (4.6cm x 3.3cm x 1.5cm) and light weight (19 grams). The device is worn around the waist with use of an elastic belt and communicates with its ActiLife® software via built-in USB connection. The ActiGraph® GT3X+ has a battery life of approximately 16 days when recording at a rate of 80 Hz. More information on the ActiGraph® GT3X+ specifications can be found in Appendix A.1.

3.3.1.1 Software

The ActiGraph® GT3X+ device communicates with ActiLife® software. This software enables the devices to be initialized to start recording at any time; for the data to be downloaded and viewed using user specified criteria; and multiple file types to be created that may be used for analysis, including epoch generated excel files. Software updates are required regularly, with the latest version used being V.6.5.3.

3.3.1.2 Initializing and downloading

Using the ActiLife® software, the ActiGraph® accelerometer is initialized which is the process that prepares the device to record data prior to the date of first wear for each participant. The ActiLife® software allows the device to be initialized several days in advance to the planned start date for recording. In most cases, the device would be initialized early in the week and set to start recording data at the start of the weekend, allowing adequate time for participants to

pick-up the device in preparation for the recording. The ActiGraph® GT3X+ device was initialized to sample at a rate of 80 Hz, for seven days of recording. Once the participant had completed and returned the week-long recording, the data were downloaded using the ActiLife® software. First, the device was plugged in and data were checked for completeness which included a wear time validation check using several methods. Second, using the ActiLife® software, wear time information was checked using user specified parameters to ensure that at least four days with 10 or more hours per day had been collected. Third, a graphing option was selected that displays the data collected on a per day basis so that data analysts can match wear time to those times that were self-reported on the Activity Monitor Log (Appendix A.3.). During this stage, postural information collected could be checked to ensure the inclinometer was functioning via graphical display of time in sitting, lying and standing. Once data were checked for completeness, the raw acceleration data were saved and stored. For data processing, this raw file was again opened using the ActiLife® software at which point an Excel spreadsheet (.csv file) was created using specified parameters that included capturing data at one second epochs. An epoch is a bin of time acceleration data can be grouped in and can range from one second to 240 seconds. Three axes of movement were captured (x, y, z) with this device. In addition, the inclinometer, steps and low frequency extension were all selected. Data at this stage were captured in one second epochs to obtain the most accurate acceleration data possible. These data could later be grouped into minutes of recording. The low frequency extension is an option that extends the lower bandwidth of normal human movement, commonly used for populations that move or take very slow steps, such as the elderly or disabled. Using this option on an older,

sedentary population ensures that slower movements are detected in, as opposed to not detecting any movement.

3.3.1.3 Data reduction and processing

Once the one second .csv files were created with the appropriate parameters selected, the data were cleaned and physical activity and sedentary behaviour variables are generated. The one second .csv file must first be grouped into one minute epochs before reduction and physical activity and sedentary behaviour variable creation takes place.

3.3.1.3.1 Reduction Algorithms

Accelerometer reduction algorithms are an automated method to remove periods of non-wear and estimate wear time. Various algorithms have been developed for the ActiGraph® device (68-71). In the current study, two algorithms were used with the ActiGraph® GT3X+ data and compared to self-reported wear time from diary data to determine which reduction algorithm is the most appropriate for large scale automated wear time estimation and data processing. The first reduction algorithm contains multiple components with the most important being the non-wear window described as a series of zero-count data that are ≥5400 seconds (i.e. 90 minutes) that are flagged as non-wear time and removed. In order to detect spurious movement within a large non-wear period, a maximum of two minutes of consecutive non-zero counts embedded within 30 minutes of upstream and downstream consecutive zero-counts is classified as non-wear (Figure 2). Any data recorded beyond seven days for a participant is removed from analysis. The second reduction algorithm used contained the same components as the first algorithm with the

exception of the zero-count window to classify periods of non-wear. This zero-count window was reduced to ≥60 minutes in duration in order to be classified as a non-wear period (Figure 2). Both algorithms were compared with the one minute data and heat maps generated. Heat maps, which are graphical representations of data with value categories represented as colors, allow for a visual representation of algorithm performance that depict periods of non-wear as well as the intensity and duration of activity throughout a day with the use of different colors. A sample of 10 files was used to compare heat maps of the two algorithms visually with the heat maps of self-reported diary information in order to select the most appropriate reduction algorithm. The algorithm that most accurately classified periods of non-wear was applied to the entire data set. In the current study, diary information of the time the monitor was put on in the morning and time it was taken off in the evening was used to accurately remove sleeping time from analysis to compare the ActiGraph® GT3X+ with the activPAL3®. For the purpose of assessing the performance of the selected automatic wear-time algorithms for the ActiGraph® device, the algorithm of choice will be used on the ActiGraph® data without the use of diary log information to remove sleeping time.

3.3.1.3.2 Computations

Once the data were cleaned, physical activity and sedentary behaviour variables were generated for use in the statistical analysis. These physical activity and sedentary behaviour variables can be split into two groups representing either the vertical axis (VT) or vector magnitude (VM). The VT variable for sedentary behaviour was <100 counts per-minute (CPM) (Table 4). For physical activity intensities, VT variables included light (100-759 CPM), lifestyle

(760-1951 CPM), moderate (1952–5724 CPM), vigorous (>5725) and moderate-to-vigorous activity (MVPA) (>1952) (Table 4). (48). For VM, estimation of sedentary behaviour was gathered from the inclinometer (i.e. sitting and lying time). For physical activity intensities, VM variables included light (<2690 CPM- sedentary behaviour), moderate (2690-6166 CPM), vigorous (6167-9642 CPM), very vigorous (>9642 CPM) and MVPA (>2691) (Table 4). (49). It was determined that estimates for vigorous and very vigorous activity for both methods of measurement, VT and VM, were too small and unstable. Therefore, these estimates are not reported alone and grouped into MVPA activity.

3.3.2 ***ActivPAL3***

The activPAL3® device is made by PAL Technologies® based in Glasgow, Scotland. The device is small (35mm x 53mm x 57mm) and weighs approximately 15 grams. The monitor is worn on the front midline portion of the right thigh and adheres to the skin with the use of PALstickies®. These adhesive pads were developed by PAL Technologies® and described as a hydro-based gel adhesive. The monitor communicates with the activPAL3 software using a USB docking station. When charged, the activPAL® can collect data for approximately 10 days duration at sampling rate of 20 Hz. More information on the activPAL3® specifications can be found in appendix A.2.

3.3.2.1 Software

The activPAL3® device communicates with its own activPAL3® software. This software enables the device to be initialized to start recording at any time, to have the data

downloaded and viewed using user-specified criteria, and to have multiple file types created that may be used for analysis, including epoch generated excel files.

3.3.2.2 Initializing and downloading

Like the ActiGraph® device, the activPAL® is initialized using its software and in most cases was initialized early in the week to start recording on the weekend. The activPAL® was packaged with the ActiGraph® device and typically sent out to participants early in the week to allow adequate time for distribution and subsequent collection by the participants. The activPAL® device is set to be initialized at a fixed sample rate of 20 Hz, for seven days of recording. Once the participant has completed and returned the week-long recording, the data had to be downloaded using the activPAL3® software. First, the device was plugged in and data were checked for completeness. The activPAL3® software displays the week's recording visually, showing a color coded day-by-day breakdown of time in sitting (yellow), standing (green) and stepping (red). Through visual inspection, data were deemed to be valid as ≥10 hours of recording for ≥four days in duration and stored for future use. During the downloading process, the activPAL3® device created seven files for potential use. The file most important for this current study is the ".pal" file, used by the activPAL3® software to produce a 15 second epoch excel file. This 15 second epoch file is similar to the one second .csv file for the ActiGraph® device which was then grouped into one minute epochs.

3.3.2.3 Data reduction and processing

Once the 15 second epoch files were created, the data was cleaned and physical activity and sedentary behaviour variables generated. The 15 second epoch file was grouped into one minute epochs before reduction and variable creation takes place. All estimates of physical activity and sedentary behaviour were reported in hours per day for each day of recording and subsequently averaged over the number of days worn to obtain a single estimate of the average hours per day in each behavior category of physical activity and sedentary behaviour.

3.3.2.3.1 Reduction Algorithms

Unlike the ActiGraph® device, no pre-determined validated algorithms exist to automatically clean the activPAL® accelerometer data. Furthermore, the activPAL® does not produce count values for each axis of recording and does not use those values to determine sedentary behavior and various activity intensities which are available with the ActiGraph®. The activPAL® does, however, provides time in a sitting or lying position through the use of its inclinometer function, which has been validated previously (6, 7). If a participant is in a seated or lying position, the activPAL® device will be in a flat or horizontal position since it is located on the front mid-line portion of the thigh. Subsequently, if a participant were to remove the monitor from their leg, the device would likely be placed in flat, horizontal position and record these data as sitting/lying time. Thus, extended periods of sitting/lying time recorded by the device could likely mean the monitor was removed. It is hypothesized then, that time sitting can be used as a surrogate indicator to determine non-wear time in an automated algorithm. In the current study, two algorithms were developed for the activPAL® device that use a window of sitting/lying time

to determine non-wear time. The first algorithm developed used a sitting/lying window of 90 minutes to indicate non-wear and the second used a window of 120 minutes. Heat maps were generated for a sample of 10 participants for each reduction algorithm and visually compared to heat maps from self-reported diary information. The visual inspection aimed to determine which algorithm most closely matched the non-wear periods removed as defined by self-report. This algorithm could subsequently be used as an automated reduction method if diary data is missing or non-existent.

3.3.3 **Activity monitor logs**

For each accelerometer recording, an activity monitor daily log book is provided with the two devices so participants can track the time the device was worn, not worn, and what activities were done during non-wear. For each day of recording, the participant filled in appropriate times including: 1) when they got up in the morning, 2) when the monitors were put on, 3) when the monitors were taken off, and 4) when they went to bed. Furthermore, space was provided for participants to fill in the times they were not wearing the monitors for ≥15 minutes in duration and what activities they were doing during this time. For the current study, the information on the times the monitors were put on and taken off as well as the duration of time the monitors were removed for any reason was used. Information on the type of activity performed during non-wear was not included in the analysis. Diary logs provide important information in order to estimate and remove non-wear time and to aid in validating appropriate non-wear algorithms for use in large-scale automated processing.

3.4 Data analysis

3.4.1 *Summary measures comparison*

All estimates of physical activity and sedentary behaviour were reported in hours per day for each day of recording and subsequently averaged over the number of days worn to get a single estimate of the average hours per day in each behavior category of physical activity and sedentary behaviour. Paired Wilcoxon tests were used in order to take into account the dependency of the data as well as the non-normality of the data using a distribution free approach.

3.4.1.1 ActiGraph® GT3X+ vs. activPAL3®

To compare the estimated time spent in physical activity and sedentary behaviour for the ActiGraph® GT3X+ and activPAL3® monitoring devices, paired Wilcoxon tests were used. The paired Wilcoxon tests were used to compare VT with activPAL3®, VM with activPAL3® and VT with VM.

3.4.1.2 ActiGraph® GT3X+ automatic wear-time estimation versus manual sleep removal

Paired Wilcoxon tests were used to compare automatic estimation of physical activity and sedentary behaviour with estimates from manual sleep removal via diary log information. Comparisons were made between automatic versus manual estimation for both VT and VM methods of measurement.

3.4.2 **Agreement**

The Bland and Altman method for multiple measures analysis will be used to assess for agreement between these two devices with regards to total time in each comparable behaviour category (78). This method includes the mean difference and 95% limits of agreement for time in activity variables of light, moderate and MVPA behavior between the two devices as well as sedentary behaviour for ActiGraph® VT, VM and the activPA3L®. Bland-Altman plots also compared VT and VM methods of measurement. Bland-Altman plots allow for the investigation of any systematic difference between measurements of physical activity and sedentary behaviour between methods. Bland-Altman plots are extensively used to evaluate and compare two methods of measurement and are preferred over measures of correlation as a high correlation does not imply agreement between methods (78).

3.4.3 **Reliability**

Intra-class correlation coefficients (ICC) were used to indicate the reliability between multiple trials of a single instrument known as the test-retest reliability (60). The intra-class correlation coefficient was estimated for each category of physical activity and sedentary behavior for both devices. For this reliability sub-study, non-wear time was manually removed using the diary log from each participant to obtain the most accurate estimate of true wearing time. This manual removal of non-wear time was feasible because of the relatively small sample size. Estimates of physical activity and sedentary behaviour were averaged over the course of the week and divided by the average estimated wear-time. These estimates were then

expressed as a percent of total-wear time in order to correct for differences in wear-time between the two recordings. Relative agreement was assessed using ICCs based on two-way mixed models without interaction

3.5 Ethical considerations

All participants provided informed consent prior to the start of the BETA Trial that included the collection of these accelerometer data and all other sources of data described here. Data pertaining to the BETA Trial were kept secure and in locked cabinets. Ethics approval was obtained from the Conjoint Health Research Ethics Board of the University of Calgary for the addition of accelerometers in the BETA Trial which was a new component of the project added after the start of the BETA Trial (Appendix A.5.).

Table 4: ActiGraph® VM, VT and activPAL3® physical activity and sedentary behaviour variables.

Activity type	ActiGraph GT3X+		activPAL3
	Vector Magnitude	**VT axis**	
Light Activity	(0-2690 cpm- SB inclinometer)	100-759 cpm	Upright – mod – vig
Moderate activity	2691-6166 cpm	1952 - 5724 cpm	3-5.9 METs
Vigorous	6167+ cpm	5725 - 9498 cpm	6+ METs
MVPA	Mod+vig (2691 - ∞)	Mod+vig (1952 - ∞)	Mod+vig
Sedentary behavior	SB-Inclinometer	SB-100 cpm	SB-Sit/Lie

Table 5: Estimated power to detect a difference in mean (min/day) between both devices with respect to sedentary behaviour. Sample sizes range from 100 to 300 individuals with standard deviations ranging from 100 to 500, encompassing what was previously reported * All estimates reported with alpha level of 0.05

Power	N	Alpha	Mean of Paired Differences	S	Effect Size
1.00000	100	0.05000	132.0	100.0	1.320
1.00000	300	0.05000	132.0	100.0	1.320
0.99173	100	0.05000	132.0	300.0	0.440
1.00000	300	0.05000	132.0	300.0	0.440
0.74356	100	0.05000	132.0	500.0	0.264
0.99531	300	0.05000	132.0	500.0	0.264

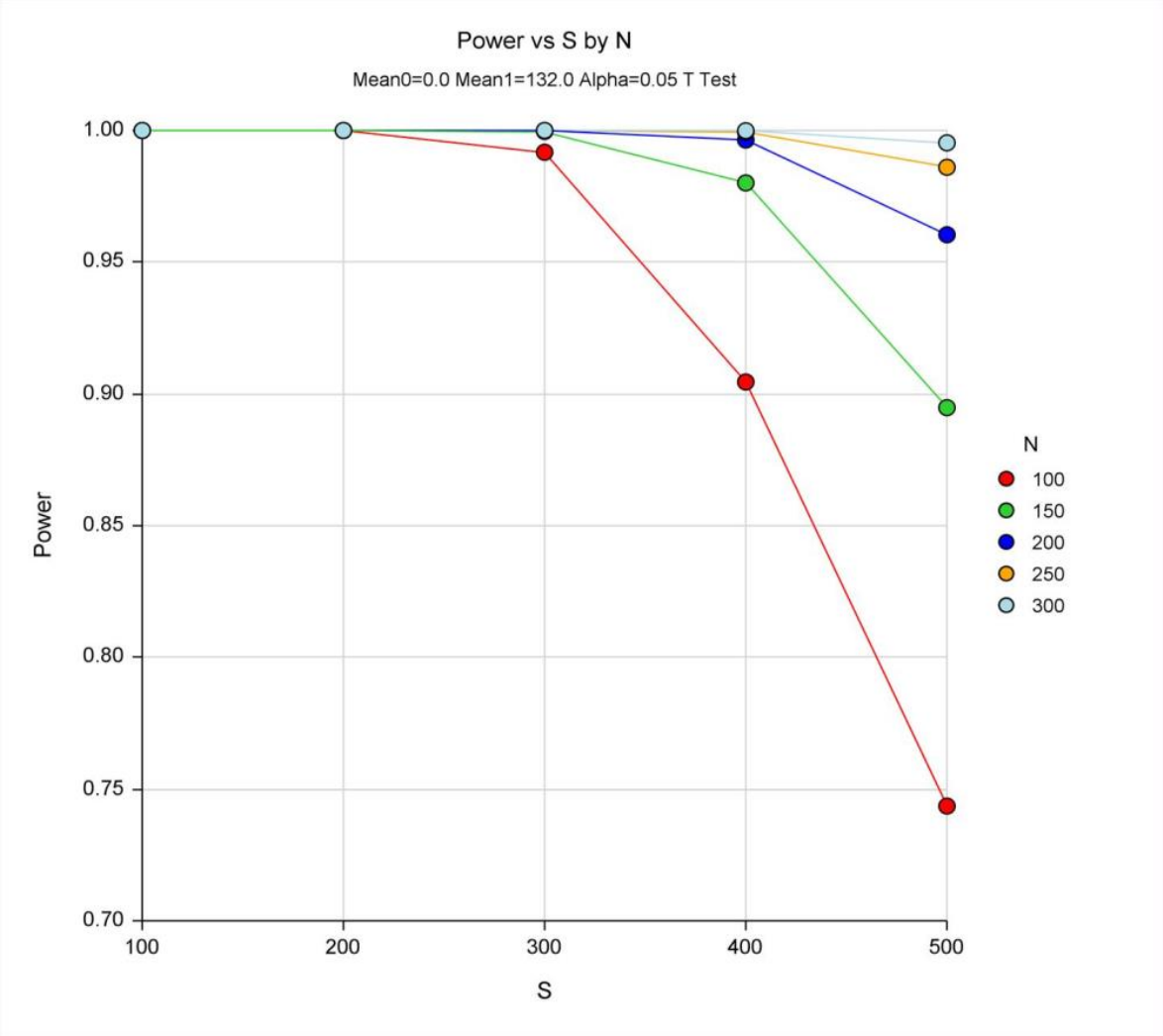


Figure 1. Power curves demonstrating losses to power as SD increases and sample size decreases.

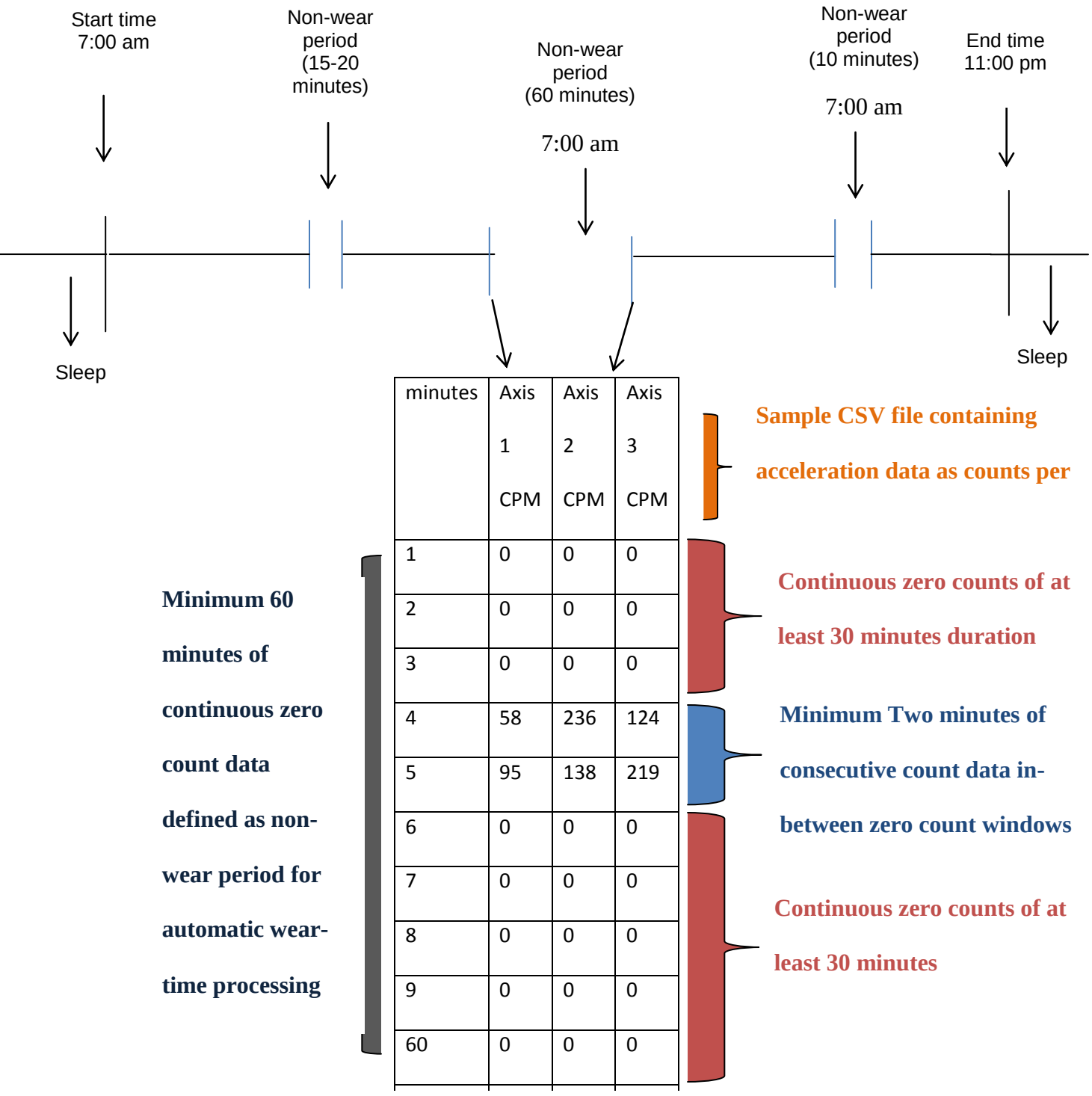


Figure 2. Automatic processing of ActiGraph® data, depicting a standard day of wear and how the automatic algorithm detects larger non-wear periods.

Chapter Four: **RESULTS**

4.1 Study sample

Of the 400 available participants from the BETA Trial, 225 participant files were available for analysis in the comparison between the ActiGraph® and the activPAL® (Figure 6). The number of files available in the comparison between devices was reduced because participants needed valid recordings for both devices, matched by day and time. Thus, if a participant had a valid recording for one device but not the other, neither recording is used in the analysis comparing devices. A total of 270 valid ActiGraph® recordings were available for analysis between manual and automatic wear-time estimation methods. This sample is slightly larger because valid ActiGraph® data did not need a matching valid activPAL® recording in the analysis comparing manual and automatic wear-time estimation.

4.2 Participant characteristics

The socio-demographic and lifestyle characteristics of the study sample are shown in Table 6. A total of 270 post-menopausal women were used in the analysis with a mean age of 59.6 years (SD=5.0 yrs), ranging from 51 to 74 years. The women were mostly Caucasian (90.7%) and well educated with the majority (79.3%) having completed college, trade school or a university degree. In addition, most were married or in common-law relationships (70.4%) and were parous (84.1%) having an average of two children each. The average age at first birth was 26.8 years (SD=5.6).

The majority of women in this sample were overweight with a mean BMI of 29.0 kg/m^2 (SD=4.6). The mean sub-cutaneous fat and intra-abdominal fat was 312.3 cm^2 (SD=97.7) and 127.0 cm^2 (SD=51.9), respectively. The mean waist circumference was 98.7 cm (SD=10.9) which exceeds the criterion cut-point for women with metabolic syndrome (79). The total past year physical activity determined by the summation of occupational (sedentary + non-sedentary), recreational, transportation and household physical activity recorded in mean hours per week was 47.4 hours (SD=20.3). The mean hours per week of household activity was 18.4 hours (SD=12.1) and recreational activity was 2.6 hours (SD=2.7). The mean hours per week spent in occupational sedentary activity was 12.6 hours (SD=12.8). The majority of time spent physically active during the week came from non-sedentary occupational activity and household activity. This sample of post-menopausal women obtained little time in recreational physical activity.

4.3 ActiGraph® GT3X+ characteristics

4.3.1 *Vertical axis*

ActiGraph® characteristics (n=225) for aggregate time (hours/day) for each behaviour of physical activity and sedentary behaviour as detected by the ActiGraph® VT axis are shown in Table 7. The mean wear time (hours/day) detected from the ActiGraph® device was 14.83 (SD=1.11). The majority of the waking day was spent in sedentary behaviour with a mean time of 8.39 hours/day (SD=1.45). The mean light activity detected was 4.21 hours/day (SD=0.89) which accounted for the majority of time spent active during the waking day. Less time was spent in those activities with increasing intensity, with mean lifestyle activity detected at 1.57 hours/day (SD=0.61), mean moderate activity estimated at 0.59 hours/day (SD=0.35) and mean

MVPA activity estimated at 0.66 hours/day (SD=0.37). Time in MVPA accounts for a fraction of total time spent active compared to light activity, which recorded almost seven times the amount of MVPA. Total sedentary time is estimated at approximately two hours more than total activity time throughout the waking day (Figure 3).

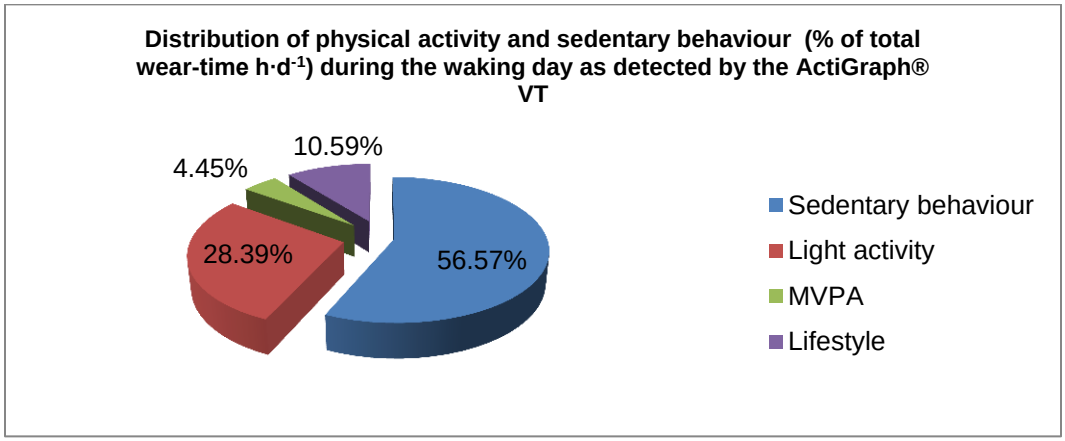


Figure 3. Distribution of physical activity and sedentary behaviour (% of total wear-time in hours/day) during the waking day as detected by ActiGraph® VT.

4.3.2 ***Vector Magnitude***

ActiGraph® characteristics (n=225) for aggregate time (hours/day) for each behaviour of physical activity and sedentary behaviour as detected by the ActiGraph® VM is shown in Table 7. Similar to the VT axis, the majority of the waking day was spent in sedentary behaviour with a mean time detected by the inclinometer of 8.67 hours/day (SD=1.66). Light intensity activity comprised the largest portion of activity time with an estimated mean time of 5.15 hours/day (SD=1.45). The mean time in moderate activity was 0.89 hours/day (SD=0.46) and for MVPA it was estimated at 1.01 hours/day (SD=0.49). Again, when the intensity of the activity increases

the time spent in those behaviours is reduced. Similar to the VT axis, time in light activity was estimated at over five times that of MVPA. With sleeping time excluded, estimated time spent in sedentary behaviour was two and a half hours more than total time spent active (Figure 4).

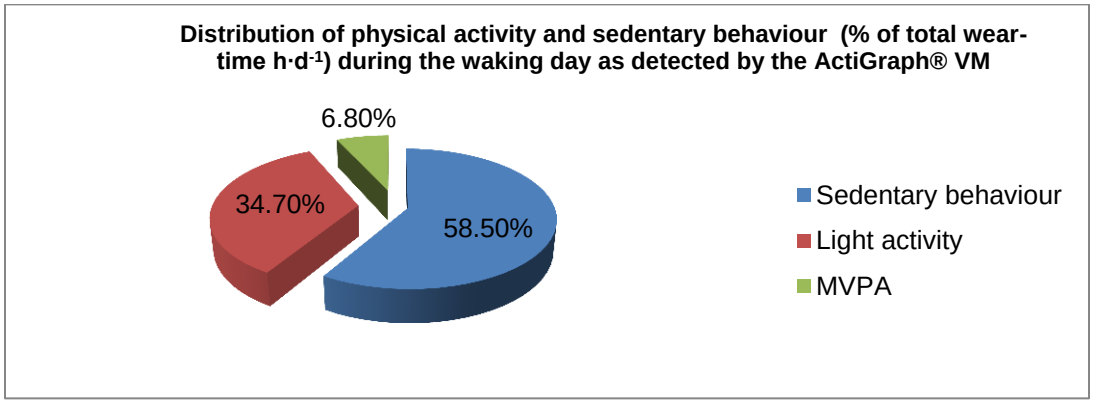


Figure 4. Distribution of physical activity and sedentary behaviour (% of total wear-time in hours/day) during the waking day as detected by ActiGraph® VM.

4.4 ActivPAL3® characteristics

The activPAL® characteristics (n=225) for behaviours of physical activity and sedentary behaviour are presented in Table 7. The mean wear time detected from the activPAL3® device was 14.86 hours/day (SD=1.10). The mean sedentary time was estimated at 8.46 hours/day (SD=1.73) which accounts for over half of the estimated mean wear-time per day. For physical activity intensities, the majority of the active day was spent in light activity with an estimated mean time of 5.50 hours/day (SD=1.57). Estimated time spent in both light activity and sedentary behaviour accounted for approximately 94% of the waking day (Figure 5). The mean

time spent in moderate and MVPA activity was 0.90 hours/day (SD=0.37). Higher intensity activities of MVPA made up a fraction (6%) of the day and total activity time (Figure 5).

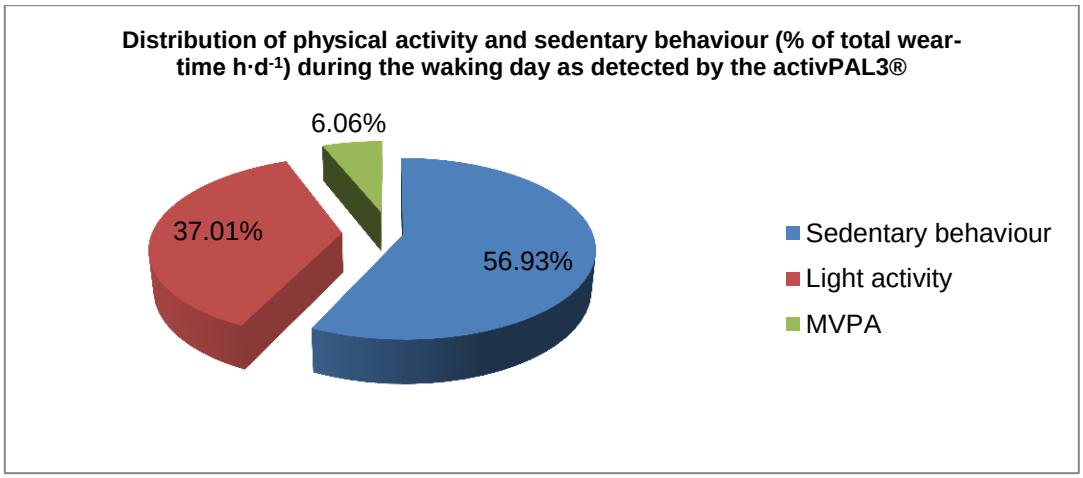


Figure 5. Distribution of physical activity and sedentary behaviour (% of total wear-time in hours/day) during the waking day as detected by activPAL3®.

4.5 Paired Wilcoxon tests

4.5.1 *ActiGraph® VT and activPAL3®*

Statistically significant differences between group median estimates (median difference ActiGraph® minus activPAL3® hours/day) of physical activity and sedentary behaviour between the ActiGraph® and activPAL3® was assessed using paired Wilcoxon tests (Table 10). Statistically significant differences were detected for all physical activity categories of light (-1.15), moderate (-0.35) and MVPA (-0.27) $p<0.001$. No statistically significant difference was found for estimated time spent in sedentary behaviour (0.04) $p=0.27$.

4.5.2 *ActiGraph® VM and activPAL3®*

Statistically significant differences in reported median estimates (median difference ActiGraph® minus activPAL3® hours/day) of physical activity and sedentary behaviour between ActiGraph® VM and activPAL3® are shown in Table 9. Statistically significant differences were found for physical activity intensities of light (-0.32) p=0.06 and MVPA (0.08) p=0.001. No statistically significant difference was found for moderate activity (-0.06) (p=0.15) or time in sedentary behaviour (0.24) p=0.48.

4.5.3 *ActiGraph® VT and ActiGraph® VM*

The differences in reported median estimates (median difference ActiGraph® VM minus VT hours/day) of physical activity and sedentary behaviour between ActiGraph® VM and vertical axis (VT) are shown in table 11. Statistically significant differences occurred across all physical activity intensities of light (0.83), moderate (0.29) and MVPA (0.35) p=0.001. Estimated time in sedentary behaviour was also statistically significantly different between the two methods of VM and VT (0.20) p=0.03.

4.6 Agreement between ActiGraph® and activPAL3®

4.6.1 *ActiGraph® VT and activPAL3®*

The level of agreement between summary measures obtained using the VT cut-count points and the activPAL3® (Table 4) was illustrated using Bland-Altman plots (Figure 11). The level of agreement is reported as the mean difference in hours per day between ActiGraph® and activPAL3® for estimates of sedentary behaviour and physical activity (95% limits of

agreement). For estimates of sedentary behaviour, the level of agreement was -0.1 (-2.3 to 2.2) hours/day. For light activity, estimated agreement was -1.3 (-3.4 to 0.9) hours/day. Estimated agreement for moderate activity was -0.32 (-0.88 to 0.24) hours/day and for MVPA it was -0.24 (-0.66 to 0.18) hours/day. For each comparable behaviour, the mean difference or bias was small. However, with the exception of moderate and MVPA activity, the 95% limits of agreement were wide, spanning several hours. The wide limits of agreement for estimates of sedentary time and light activity may indicate that these two devices cannot be used interchangeably to estimate these behaviours. Despite the narrow limits of agreement for estimates of moderate activity and MVPA between the two devices, these particular activity intensities are rare throughout the waking day. Therefore, small variations of only an hour in estimating these activities categories may be too large to use these devices interchangeably.

4.6.2 ***ActiGraph® VM and activPAL3®***

The level of agreement between comparable behaviours of sedentary time and physical activity intensities as detected by ActiGraph® VM and activPAL3® (Table 4) were illustrated using Bland-Altman plots (Figure 12). The level of agreement is reported as the mean difference between ActiGraph® and activPAL3® for time in sedentary behaviour and physical activity (95% limits of agreement). For sedentary time, the level of agreement was 0.2 (-3.9 to 4.3) hours/day. For light intensity activity, estimated agreement was -0.4 (-4.3 to 3.6) hours/day. Estimated agreement for moderate activity was -0.01 (-0.78to 0.75) hours/day and for MVPA it was 0.11 (-0.56 to 0.78) hours/day. The mean difference for each comparable behaviour category was small. Despite this small difference, the limits of agreement are wide for each

behaviour category, with the largest limits of agreement observed for sedentary behaviour and light activity while the smallest was observed for moderate activity and MVPA. These wide limits of agreement suggest that these two devices cannot be used interchangeably to estimate physical activity and sedentary behaviour.

4.6.3 *ActiGraph® VT and ActiGraph® VM*

The level of agreement between ActiGraph® VM and VT methods of measurement are shown using Bland-Altman plots (Figure 13) and reported as the mean difference between VM and VT for estimated time in sedentary behaviour and physical activity (95% limits of agreement). The smallest mean difference between methods occurred for estimated time in sedentary behaviour at 0.3 (-3.2 to 3.8) hours/day. The largest mean difference between methods occurred for light intensity activity estimated at 0.9 (-2.4 to 4.2) hours/day. The mean difference between VM and VT was small for moderate and MVPA activity at 0.30 hours/day (-0.22 to 0.83) and 0.35 hours/day (-0.16 to 0.86), respectively. The limits of agreement are wide for each behaviour category, with the largest limits of agreement observed for sedentary behaviour and light activity while the smallest was observed for moderate activity and MVPA. These wide limits of agreement suggest that these two methods of measurement from the ActiGraph® device cannot be used interchangeably to estimate physical activity and sedentary behaviour.

4.7 Behavioural variation (test-retest reliability)

Behavioural variation for each method of ActiGraph® VM, VT and activPAL3® was estimated using Intraclass correlation coefficients (ICC) and reported as (ICC (95% CI)) (Table

14). Behavioural variation was estimated from week-to-week with high reliability for estimates of sedentary behaviour and physical activity indicating that researchers who have participants record at least one week of data are obtaining reliable estimates of habitual patterns of activity or sedentary behaviour.

4.7.1 *ActiGraph® VM*

The absolute reliability was high and similar across all physical activity intensities of light (0.87 (0.73 to 0.94)), moderate (0.88 (0.75 to 0.95)), vigorous (0.87 (0.72 to 0.9)) and MVPA (0.88 (0.75 to 0.94)) (Table 14). The estimated reliability for time spent in sedentary behaviour was the highest of all behaviour categories (0.91 (0.81 to 0.96)). Across all estimates of physical activity and sedentary behaviour, the ICCs demonstrate that the absolute reliability is good. Sedentary behaviour demonstrates the least behavioural variation between the two recordings. These data indicate that the variation from week to week is minimal in a free living condition when the device is worn for at least four days each week.

4.7.2 *ActiGraph® VT*

Estimated reliability was high and similar for activity intensities of light (0.84 (0.67 to 0.93)) and vigorous (0.89 (0.77 to 0.95)). Reliability estimates were low and similar for activities of moderate (0.66 (0.30 to 0.84)) and MVPA (0.67 (0.31 to 0.84)), demonstrating increased behavioural variation from week-to-week for these activities. Similar to the ActiGraph® VM, the estimated reliability for time spent in sedentary behaviour was the highest of all behaviour

categories (0.93 (0.86 to 0.97)). The ICCs reported for light and vigorous activity was consistent with that reported using ActiGraph® VM (Table 14).

4.7.3 ***activPAL3®***

The absolute reliability was high and consistent across each category of physical activity and sedentary behaviour (Table 14). Reliability estimates for physical activity found light intensity activity to have the least behavioural variation from week-to-week (0.89 (0.76 to 0.95)) with slightly lower estimated reliability for moderate and MVPA (0.82 (0.63 to 0.92)). Similar to the ActiGraph® device, the absolute reliability for time in sedentary behaviour was high (0.90 (0.80 to 0.95)). These results indicate the activPAL3® device is capable of providing reliable estimates of habitual physical activity and sedentary behaviour patterns when the device is worn for at least one week.

4.8 Estimating Wear Time

4.8.1 ***ActiGraph® GT3X+***

Algorithms have been previously developed for the ActiGraph® device to determine wear and non-wear periods automatically in the absence of diary log information (68-71). This study has implemented two variations of a previously developed and validated algorithm in order to find the one that best suits the population under investigation.

4.8.1.1 90 minute zero-count window

This algorithm has been described previously, containing a minimum 90 minute zero-count window for detection of non-wear periods (71). In order to excuse potential spurious counts that can occur within a true non-wear period, two minutes of consecutive count data or "spikes" are allowed with 30 minutes of zero-counts both before and after the spikes occur. Allowing spurious movement within larger non-wear periods that are likely true non-wear assists in the proper classification of wear-time. Heat maps were produced for a small sample of 10 individuals in order to compare algorithm performance with diary log information. Figure 8 show the results for one participant with complete diary log wear time information and respective heat map. From these figures, it appears that no false non-wear periods were detected; however, the 90 minute window does not detect larger non-wear periods that are around 60 minutes in duration. One potential explanation is because these participants were in an intervention trial and had been asked to adhere to the directions of wearing the device for the waking day. Therefore, device removal is likely for brief periods and a smaller window is more likely to catch both smaller and larger removal times.

4.8.1.2 60 minute zero-count window

This algorithm uses a smaller non-wear window of 60 minutes. The Heat map for one participant that incorporate this algorithm and corresponding diary log information is shown in figure 7. From these figures, it appears that the 60 minute non-wear window correctly detected larger non-wear periods as determined via diary log and no false non-wear periods were detected. Based on these two algorithms, the smaller 60 minute window performed better than

the 90 minute window. Despite this increase in performance, neither algorithm is able to classify very small non-wear periods correctly (e.g. 15 minutes). This result is expected, as small non-wear windows of time are more likely to classify wear-time as non-wear.

4.8.2 ***activPAL3®***

No wear-time algorithms have previously been developed for the activPAL® device. One method applied in this study used prolonged sitting time detected by the activPAL® as a surrogate measure for potential non-wear. For this study, a window of sitting time was used in a similar fashion as the algorithms employed for the ActiGraph® GT3X+. The first algorithm used a 90 minute window of continuous sitting time to classify non-wear. Two minutes of non-sitting time (spikes) with 30 minutes of sitting both before and after where the spikes occurred allows for potential spurious movement within a true non-wear period. Figure 10 demonstrates this automatic approach compared to diary log information. It is clear that this method of using 90 minutes of sitting time detects many false non-wear periods. Furthermore, figure 9 demonstrates the use of a smaller 60-minute non-wear window which continues to detect false non-wear periods. This approach of using sitting time to determine non-wear, despite testing multiple windows of prolonged sitting, does not accurately estimate wear-time for the activPAL® device.

4.9 Automatic estimation of physical activity and sedentary behaviour compared to manual sleep removal for the ActiGraph® GT3X+

4.9.1 ***ActiGraph®characteristics***

For the comparison of automated and manual estimation of physical activity and sedentary behaviour for the ActiGraph® device, the total number of valid participant files increased (n=270). By using only available ActiGraph® data, valid days of recording do not need to be matched with valid days from the activPAL3®. This study had more valid days of recording from the ActiGraph® device; therefore more files were available for analysis between automatic and manual methods of estimating physical activity and sedentary behaviour. The algorithm with a 60 minute zero-count window used to detect non-wear periods was compared to manual sleep removal from diary log information.

4.9.1.1 ActiGraph® VT

4.9.1.1.1 ActiGraph® VT automatic

The mean wear time (hours/day) detected from the ActiGraph® device determined from the average for each participant (n=270) was 14.94 hours/day (SD=1.14) (Table 8). The majority of time was spent in sedentary behaviour with a mean time of 8.31 hours/day (SD=1.48). Light intensity activity accounted for the majority of activity time at 4.31 hours/day (SD=0.88). Higher intensity activities accounted for a smaller portion of total activity time with mean lifestyle activity detected at 1.64 hours/day (SD=0.63), mean moderate activity detected at 0.60 hours/day (SD=0.35) and mean MVPA activity at 0.68 hours/day (SD=0.37) (Table 8). Time in sedentary behaviour accounted for approximately 56% of the total waking day, with light activity accounting for approximately 65% of total activity time.

4.9.1.1.2 **ActiGraph® VT manual**

The mean wear time (hours/day) detected from the ActiGraph® device determined from the average for each participant (n=270) was 14.87 hours/day (SD=1.10) (Table 8). The majority of time was spent in sedentary behaviour with a mean time 8.38 hours/day (SD=1.44), approximately 56% of total wear- time. Total activity time accounted for approximately 44% of wear-time with the majority coming from light intensity activity with a mean time of 4.22 hours/day (SD=0.88). Higher intensity activities account for a small portion of overall activity time. The mean lifestyle activity was estimated at 1.60 hours/day (SD=0.63), mean moderate activity at 0.59 hours/day (SD=0.34) and MVPA with an estimated mean of 0.67 hours/day (SD=0.36).

4.9.1.2 ActiGraph® VM

4.9.1.2.1 ActiGraph® VM automatic

The mean wear time (hours/day) detected from the ActiGraph® (n=270) was 14.94 hours/day (SD=1.14) (Table 8). Mean sedentary time 8.82 hours/day (SD=1.63) accounted for the majority of the waking day. The largest portion of time spent active was in light intensity activity with a mean value of 5.07 hours/day (SD=1.43). The mean moderate activity detected was 0.93 hours/day (SD=0.47) and mean MVPA activity 1.06 hours/day (SD=0.51). These higher intensity activities comprised a small portion of total activity time. Over half of the waking day was spent in sedentary behaviour. The most prevalent behaviours of sedentary time and light activity accounted for approximately 94% of the waking day.

4.9.1.2.2 ActiGraph® VM manual

The mean sedentary time (hours/day) was estimated at 8.64 hours/day (SD=1.64) taking up the largest portion of waking day (Table 8). Similar to automatic wear-time estimation, the mean light activity detected was 5.19 hours/day (SD=1.42). The mean moderate activity detected was 0.91 hours/day (SD=0.47) and mean MVPA activity was 1.04 hours/day (SD=0.50). The higher intensity activities (MVPA) accounted for a small fraction of total activity time, approximately 7% of the waking day. Time in sedentary behaviour was estimated at over half of the total day, with sedentary time and light activity combining for 93% of the waking day.

4.9.2 ***Paired Wilcoxon tests***

4.9.2.1 ActiGraph® VM automatic versus manual

Significant differences in reported mean estimates of physical activity and sedentary behaviour between the ActiGraph® GT3X+ automatic and manual wear-time estimation methods were assessed using paired Wilcoxon tests (Table 12). Significant differences were found across all behaviour categories of light, moderate, MVPA and sedentary time ($p<0.0001$). Automatic estimation resulted in higher reported estimates for moderate, MVPA and sedentary time. For estimates of light activity, automatic estimation resulted in significantly less time compared to manual sleep removal. The mean difference between methods were quite small, however, for behaviour categories of light activity and sedentary behaviour this mean difference appeared to be higher than expected compared to moderate and MVPA activity. Thus, the automated approach used may be biased to underestimating light activity and overestimating time in sedentary behaviour.

4.9.2.2 ActiGraph® VT automatic versus manual

Differences in reported mean estimates of physical activity and sedentary behaviour between the ActiGraph® GT3X+ automatic and manual wear-time estimation methods were also assessed using paired Wilcoxon tests (Table 13). Statistically significant differences were found across all physical activity categories of light, moderate and MVPA ($p<0.0001$). Estimated time in sedentary behaviour was also statistically significantly different between the automatic and manual approach ($p=0.0004$). The mean difference between methods was small despite the low p-values for each behaviour category.

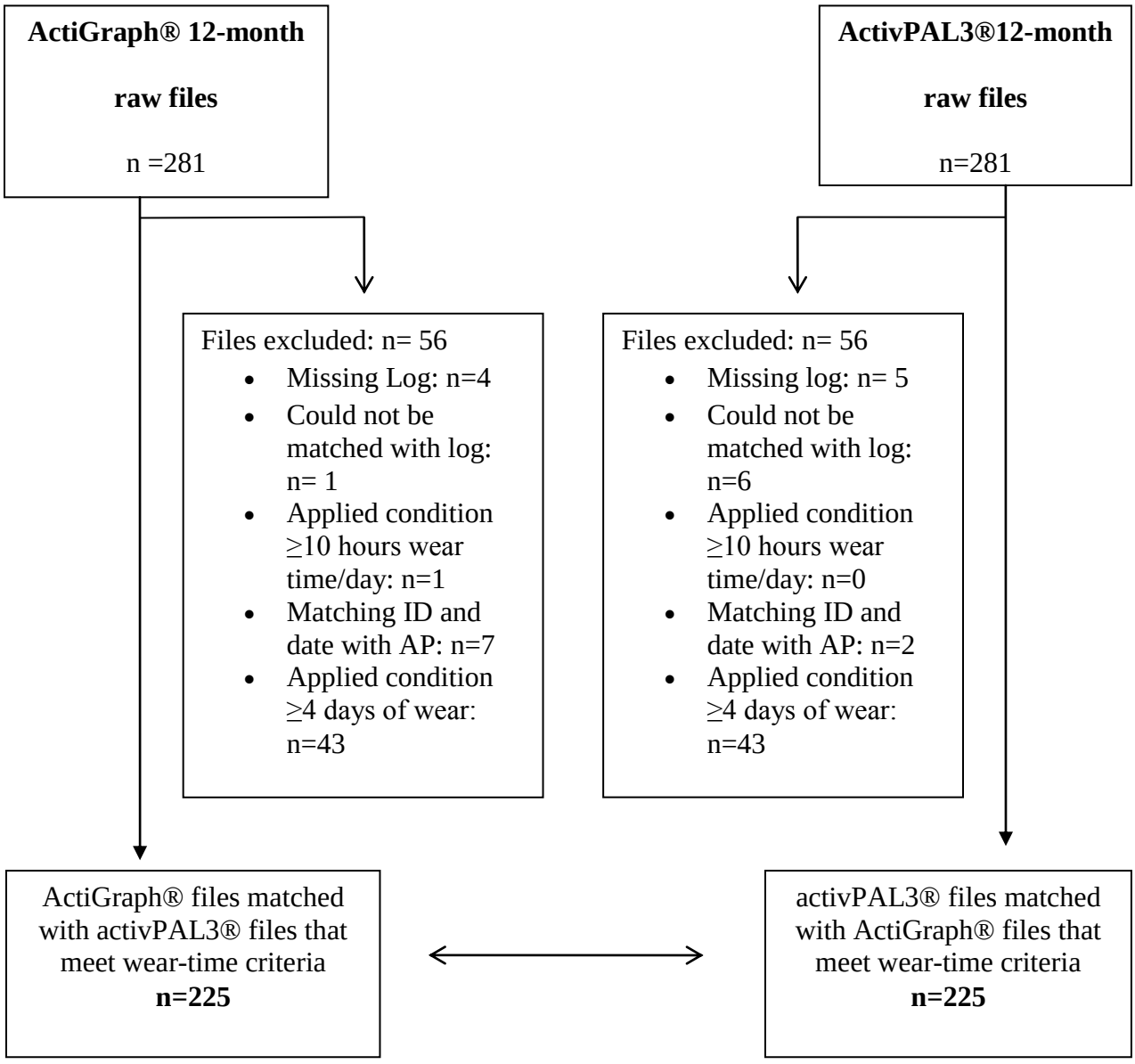


Figure 6. Valid accelerometer files flow chart

Table 6: Descriptive baseline characteristics for study participants included in accelerometer project and for the entire BETA Trial study sample, Alberta, 2010-2011.

Variable	N	Mean (SD)	Median	Range
Age (years)	[a]270 *[b]400*	[a]59.6 (5.0) *[b]59.4 (5.0)*	[a]58.4 *[b]58.3*	[a]51-74.4 *[b]50.3-74.4*
Age at first birth (years)	[a]227 *[b]336*	[a]26.8 (5.6) *[b]26.5 (5.4)*	[a]26 *[b]26*	[a]16-44 *[b]16-44*
Live births (number)	[a]233 *[b]399*	[a]2.3 (1.1) *[b]2.3 (1.1)*	[a]2 *[b]2*	[a]0-7 *[b]0-8*
Age at menarche (years)	[a]269 *[b]399*	[a]12.8 (1.6) *[b]12.9 (1.5)*	[a]13 *[b]13*	[a]8-19 *[b]8-19*
Age at menopause (years)	[a]270 *[b]400*	[a]49.4 (5.1) *[b]49.3 (5.2)*	[a]50 *[b]50*	[a]28-60 *[b]28-60*
Body mass index (kg/m^2)	[a]270 *[b]400*	[a]29.0 (4.6) *[b]29.3 (4.4)*	[a]28.0 *[b]28.6*	[a]21.8-40.3 *[b]21.8-40.3*
Waist circumference (cm)	[a]270 *[b]400*	[a]98.7 (10.9) *[b]98.7 (10.9)*	[a]97.8 *[b]97.8*	[a]65-129.2 *[b]65-129.2*
Intra-abdominal fat (cm^2)	[a]270 *[b]400*	[a]127.0 (51.9) *[b]129.5 (50.2)*	[a]120.2 *[b]123.1*	[a]27.6-296.9 *[b]21.33-296.9*
Sub-cutaneous fat (cm^2)	[a]270 *[b]400*	[a]312.3 (97.7) *[b]314.0 (98.3)*	[a]311.2 *[b]310.4*	[a]75.0-640.3 *[b]75.0-640.3*
Total Past year physical activity (Mean Hours/week)	[a]266 *[b]394*	[a]47.4 (20.3) *[b]46.8 (19.9)*	[a]45.3 *[b]45.3*	[a]6.5-142.9 *[b]0.04-142.9*

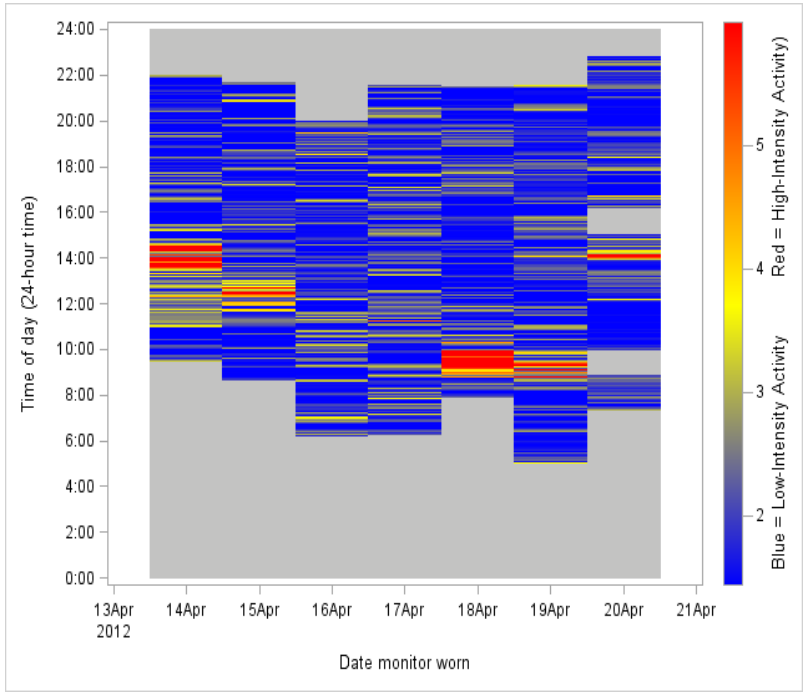
Variable	Frequency	Percent
Education		
University degree	[a]133 [b]*189*	[a]49.3 [b]*47.3*
College or trade school	[a]81 [b]*121*	[a] 30.0 [b]*30.3*
High school or less	[a]56 [b]*90*	[a]20.7 [b]*22.5*
Marital status		
Married/common-law	[a]190 [b]*275*	[a]70.4 [b]*68.8*
Divorced/separated	[a]55 [b]*85*	[a]20.4 [b]*21.3*
Widowed/never married	[a]25 [b]*40*	[a]9.3 [b]*10*
Ethnic origin		
Caucasian	[a]245 [b]*358*	[a]90.7 [b]*89.5*
Other	[a]25 [b]*42*	[a]9.3 [b]*10.5*

[a] Values estimated on the project study sample (n=270)

[b] Values estimated for the entire BETA Trial study sample (n=400)

Figure 7. Heat maps comparing the 60-minute automatic non-wear removal and diary log reported non-wear for the ActiGraph® GT3X+. Grey areas in automatic processing indicate non-wear (left) and red areas indicate non-wear in the diary log (right).

a) automatic wear-time processing



b) Diary log indicated non-wear

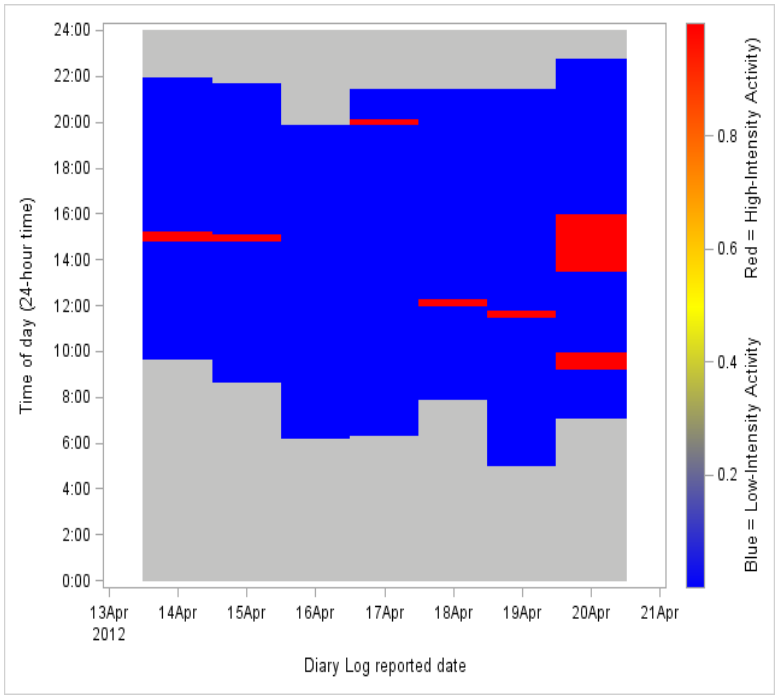
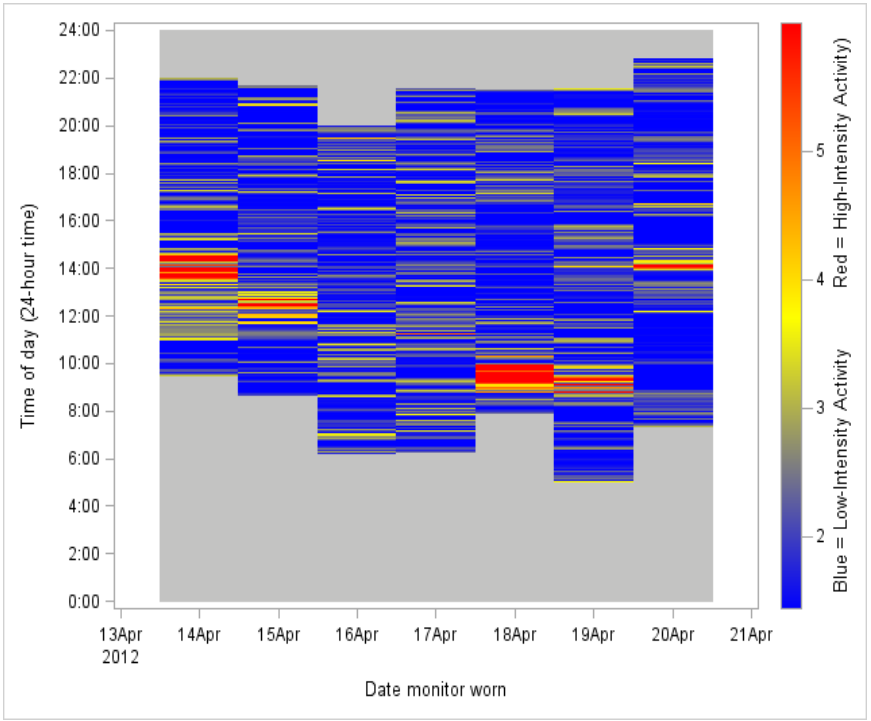


Figure 8. Heat maps comparing the 90-minute automatic non-wear removal and diary log reported non-wear for the ActiGaraph® GT3X+. Grey areas in automatic processing indicate non-wear (left) and red areas indicate non-wear in the diary log (right).

a) Automatic wear-time processing



b) Diary log non-wear removal

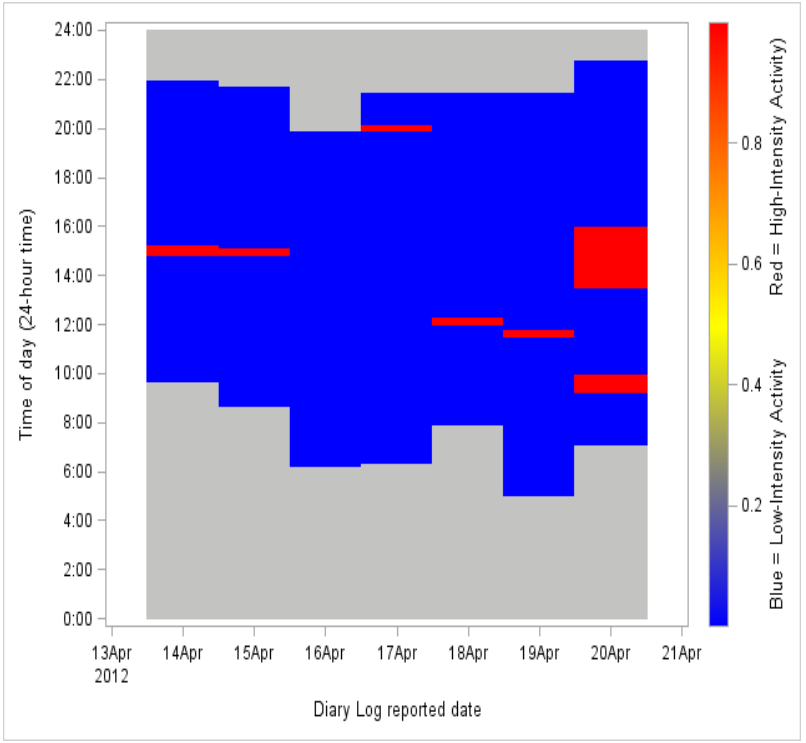
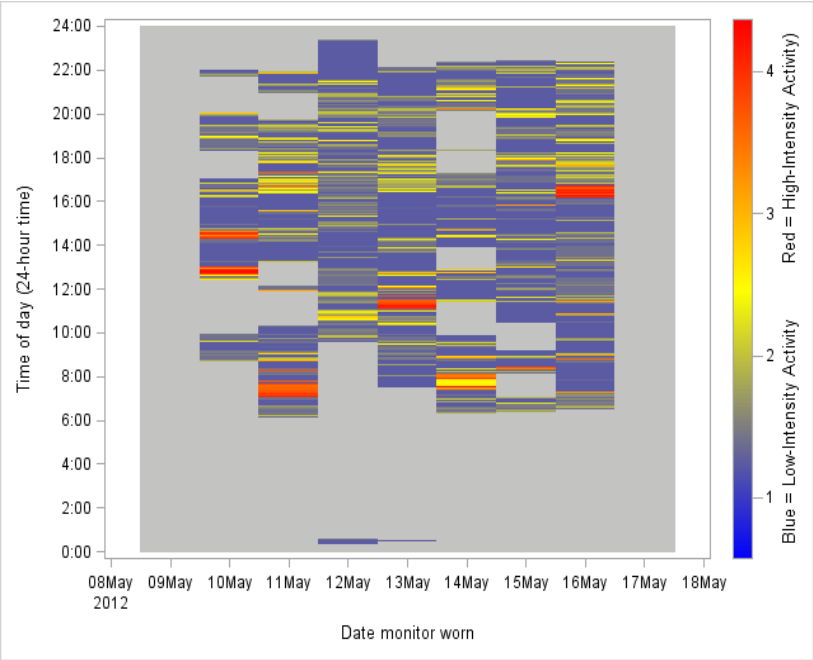


Figure 9. Heat maps comparing the 60-minute automatic non-wear removal and diary log reported non-wear for the activPAL3®. Grey areas in automatic processing indicate non-wear (left) and red areas indicate non-wear in the diary log (right).

a) Automatic processing



b) Diary log indicated non-wear

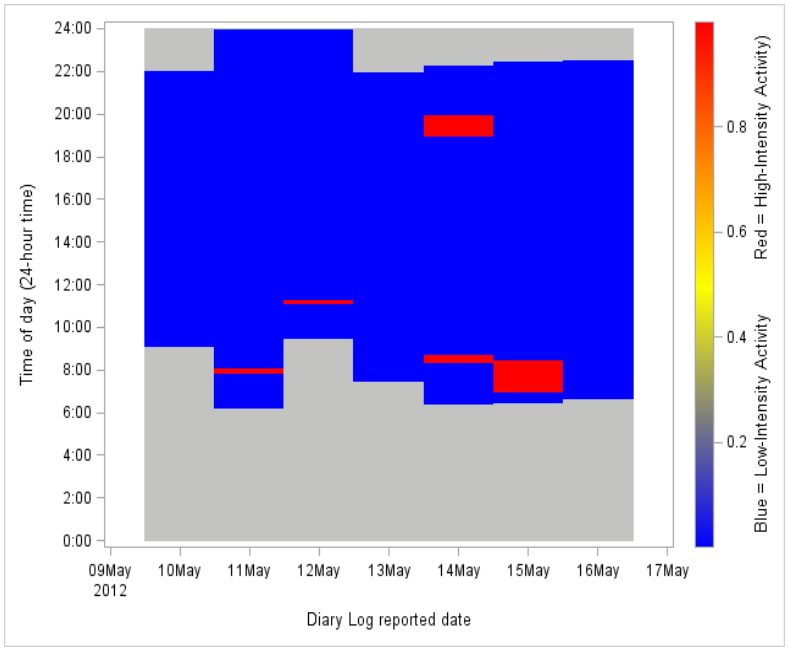
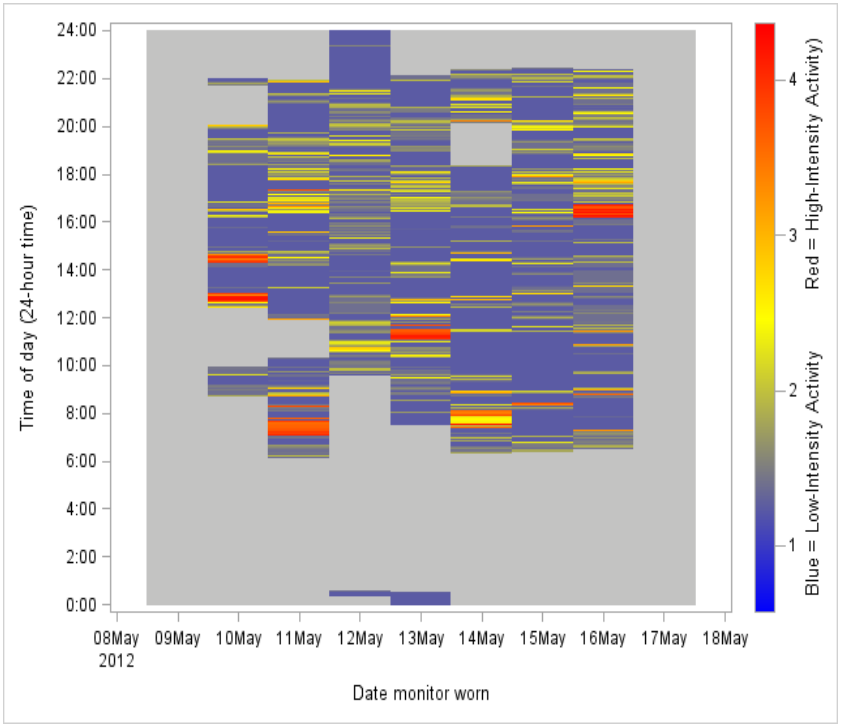


Figure 10. Heat maps comparing the 90-minute automatic non-wear removal and diary log reported non-wear for the activPAL3®. Grey areas in automatic processing indicate non-wear (left) and red areas indicate non-wear in the diary log (right).

a) Automatic processing



b) Diary log indicated non-wear

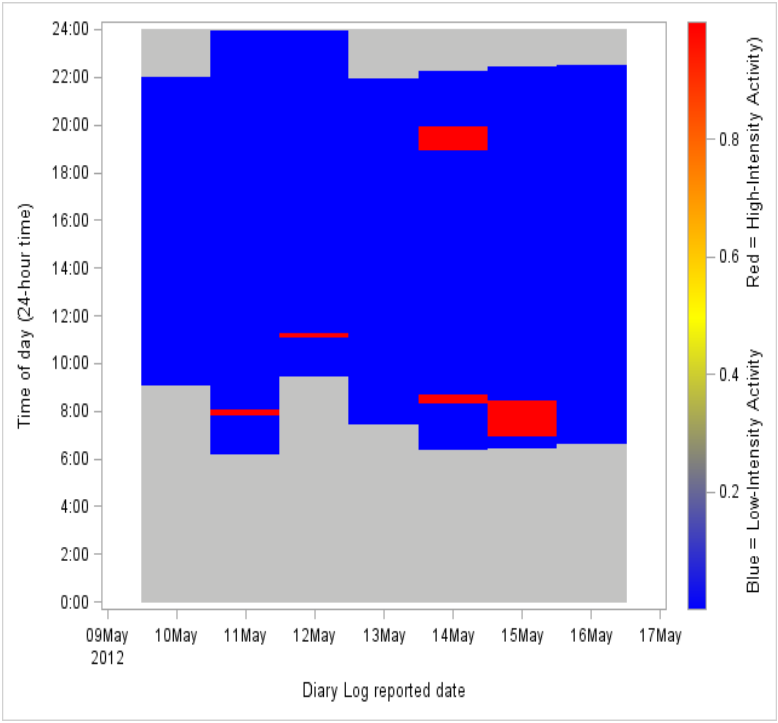


Table 7: ActiGraph® GT3X+ VM, VT and activPAL3® characteristics (hours/day).

ActiGraph®	**N**	**Mean (SD)**	**Median**	**Range**
Wear time ($h \cdot d^{-1}$)	225	14.83 (1.11)	14.85	11.52-18.19
Vertical Axis				
Sedentary ($h \cdot d^{-1}$, 100 cpm)	225	8.39 (1.45)	8.55	4.44-11.59
Active ($h \cdot d^{-1}$, 100+ cpm)	225	6.44 (1.41)	6.39	2.92-10.57
Light activity ($h \cdot d^{-1}$, 100–759 cpm)	225	4.21 (0.89)	4.23	2.27-6.71
Lifestyle activity ($h \cdot d^{-1}$, 760–1951 cpm)	225	1.57 (0.61)	1.42	0.53-3.14
Moderate activity ($h \cdot d^{-1}$, 1952–5724 cpm)	225	0.59 (0.35)	0.53	0.02-2.25
MVPA ($h \cdot d^{-1}$, 1952+ cpm)	225	0.66 (0.37)	0.62	0.02-2.31
Vector Magnitude				
Sedentary ($h \cdot d^{-1}$, Inclinometer)	225	8.67 (1.66)	8.75	4.13-12.96
Active ($h \cdot d^{-1}$)	225	6.16 (1.58)	6.09	2.39-10.13
Light activity ($h \cdot d^{-1}$, 0-2690 cpm- sedentary behaviour inclinometer)	225	5.15 (1.45)	5.06	1.22-8.67
Moderate activity ($h \cdot d^{-1}$, 2691-6166 cpm)	225	0.89 (0.46)	0.82	0.14-2.92
MVPA ($h \cdot d^{-1}$, Mod+vig (2691 - ∞)	225	1.01 (0.49)	0.97	0.14-3.02

activPAL3®	**N**	**Mean (SD)**	**Median**	**Range**
Wear time ($h \cdot d^{-1}$)	225	14.86 (1.10)	14.91	11.52-18.19
Sedentary ($h \cdot d^{-1}$, Sit/Lie)	225	8.46 (1.73)	8.51	4.11-12.78

Active ($h \cdot d^{-1}$)	225	6.41 (1.67)	6.30	2.27-10.77
Light activity ($h \cdot d^{-1}$, Upright – mod – vig)	225	5.50 (1.57)	5.38	1.99-9.52
Moderate activity ($h \cdot d^{-1}$ 3-5.9 METs)	225	0.90 (0.37)	0.89	0.10-2.69
MVPA ($h \cdot d^{-1}$ 6+ METs)	225	0.90 (0.37)	0.89	0.10-2.69

Table 8: ActiGraph® GT3X+ VT and VM characteristics for automatic and manual wear-time estimation (hours/day).

ActiGraph® VT (Automated)	**N**	**Mean (SD)**	**Median**	**Range**
Wear time ($h \cdot d^{-1}$)	270	14.94 (1.14)	15.01	11.28-18.19
Sedentary ($h \cdot d^{-1}$, 100 cpm)	270	8.31 (1.48)	8.41	4.38-11.82
Active ($h \cdot d^{-1}$, 100+ cpm)	270	6.63 (1.41)	6.57	3.11-10.62
Light activity ($h \cdot d^{-1}$, 100–759 cpm)	270	4.31 (0.88)	4.27	2.29-7.33
Lifestyle activity ($h \cdot d^{-1}$, 760–1951 cpm)	270	1.64 (0.63)	1.50	0.49-3.59
Moderate activity ($h \cdot d^{-1}$, 1952–5724 cpm)	270	0.60 (0.35)	0.55	0.02-2.28
MVPA ($h \cdot d^{-1}$, 1952+ cpm)	270	0.68 (0.37)	0.65	0.02-2.32
ActiGraph® VT (Manual)	**N**	**Mean (SD)**	**Median**	**Range**
Wear time ($h \cdot d^{-1}$)	270	14.87 (1.10)	14.93	11.52-18.19
Sedentary ($h \cdot d^{-1}$, 100 cpm)	270	8.38 (1.44)	8.50	4.67-11.56
Active ($h \cdot d^{-1}$, 100+ cpm)	270	6.49 (1.41)	6.42	2.93-10.57
Light activity ($h \cdot d^{-1}$, 100–759 cpm)	270	4.22 (0.88)	4.18	2.27-7.24
Lifestyle activity ($h \cdot d^{-1}$, 760–1951 cpm)	270	1.60 (0.63)	1.45	0.48-3.59
Moderate activity ($h \cdot d^{-1}$, 1952–5724 cpm)	270	0.59 (0.34)	0.54	0.02-2.25

MVPA ($h \cdot d^{-1}$, 1952+ cpm)	270	0.67 (0.36)	0.63	0.02-2.31

ActiGraph® VM (Automated)	**N**	**Mean (SD)**	**Median**	**Range**
Sedentary ($h \cdot d^{-1}$, Inclinometer)	270	8.82 (1.63)	8.90	3.40-13.14
Active ($h \cdot d^{-1}$,)	270	6.13 (1.58)	6.06	2.26-10.98
Light activity ($h \cdot d^{-1}$, 0-2690 cpm-sedentary behaviour inclinometer)	270	5.07 (1.43)	4.89	1.35-8.58
Moderate activity ($h \cdot d^{-1}$, 2691-6166 cpm)	270	0.93 (0.47)	0.86	0.17-2.93
MVPA ($h \cdot d^{-1}$, Mod+vig (2691 - ∞)	270	1.06 (0.51)	1.02	0.17-3.04

ActiGraph® VM (Manual)	**N**	**Mean (SD)**	**Median**	**Range**
Sedentary ($h \cdot d^{-1}$, Inclinometer)	270	8.64 (1.64)	8.69	3.71-12.96
Active ($h \cdot d^{-1}$,)	270	6.23 (1.56)	6.23	2.39-11.22
Light activity ($h \cdot d^{-1}$, 0-2690 cpm-sedentary behaviour inclinometer)	270	5.19 (1.42)	5.09	1.22-8.67
Moderate activity ($h \cdot d^{-1}$, 2691-6166 cpm)	270	0.91 (0.47)	0.83	0.14-2.92
MVPA ($h \cdot d^{-1}$, Mod+vig (2691- ∞)	270	1.04 (0.50)	1.00	0.14-3.02

Table 9: Paired Wilcoxon tests comparing estimates of physical activity and sedentary behaviour (hours/day) between the ActiGraph® GT3X+ VM and the activPAL3®.

Activity type	ActiGraph® GT3X+ (VM) **Median (95% CI) hrs**	Interquartile Range (AG)	activPAL3® **Median (95% CI) hrs**	Interquartile Range (AP)	Wilcoxon test p-value (α=0.05)
Light Activity	5.06 (4.82 to 5.38)	4.21 to 6.21	5.38 (5.27 to 5.65)	4.25 to 6.71	p=0.050
Moderate activity	0.82 (0.75 to 0.90)	0.52 to 1.15	0.89 (0.84 to 0.95)	0.65 to 1.14	p=0.154
MVPA	0.97 (0.85 to 1.02)	0.64 to 1.32	0.89 (0.84 to 0.95)	0.65 to 1.14	p=0.0001
Sedentary	8.75 (8.44 to 9.01)	7.65 to 9.84	8.51 (8.15 to 8.82)	7.31 to 9.78	p=0.480

Table 10: Paired Wilcoxon tests comparing estimates of physical activity and sedentary behaviour (hours/day) between the ActiGraph® GT3X+ VT and the activPAL3®.

Activity type	ActiGraph® GT3X+ (VT) **Median (95% CI) hrs**	Interquartile Range (AG)	activPAL3® **Median (95% CI) hrs**	Interquartile Range (AP)	Wilcoxon test p-value (α=0.05)
Light Activity	4.23 (3.96 to 4.36)	3.47 to 4.87	5.38 (5.27 to 5.65)	4.25 to 6.71	p<0.0001
Moderate activity	0.53 (0.48 to 0.57)	0.33 to 0.77	0.88 (0.84 to 0.95)	0.65 to 1.14	p<0.0001
MVPA	0.62 (0.56 to 0.68)	0.39 to 0.88	0.89 (0.84 to 0.95)	0.65 to 1.14	p<0.0001
Sedentary	8.55 (8.25 to 8.83)	7.41 to 9.41	8.51 (8.15 to 8.82)	7.31 to 9.78	p=0.2690

Table 11: Paired Wilcoxon tests comparing estimates of physical activity and sedentary behaviour (hours/day) between the ActiGraph® GT3X+ VM and VT methods of measurement.

Activity type	ActiGraph® GT3X+ (VM) **Median (95% CI) hrs**	Interquartile Range (AG)	ActiGraph® GT3X+ (VT) **Median (95% CI) hrs**	Interquartile Range (AP)	Wilcoxon test p-value (α=0.05)
Light Activity	5.06 (4.82 to 5.38)	4.21 to 6.21	4.23 (3.96 to 4.36)	3.47 to 4.87	p<0.0001
Moderate activity	0.82 (0.75 to 0.90)	0.52 to 1.15	0.53 (0.48 to 0.57)	0.33 to 0.77	p<0.0001
MVPA	0.97 (0.87 to 1.07)	0.64 to 1.32	0.61 (0.56 to 0.67)	0.38 to 0.87	p<0.0001
Sedentary	8.75 (8.44 to 9.01)	7.65 to 9.84	8.55 (8.25 to 8.83)	7.41 to 9.41	p=0.0282

Table 12: Paired Wilcoxon tests comparing the ActiGraph® GT3X+ Vector Magnitude (VM) estimates of physical activity and sedentary behaviour (hours/day) between automated and manual sleep removal methods.

Activity type	ActiGraph® GT3X+ (Auto) **Median (95% CI) hrs**	Interquartile Range (AG)	ActiGraph® GT3X+ (sleep removed) **Median (95% CI) hrs**	Interquartile Range (AP)	Wilcoxon test p-value (α=0.05)
Light Activity	4.89 (4.74 to 5.12)	4.09 to 6.10	5.09 (4.89 to 5.39)	4.20 to 6.23	p<0.0001
Moderate activity	0.86 (0.79 to 0.92)	0.57 to 1.23	0.83 (0.77 to 0.91)	0.55 to 1.22	p<0.0001
MVPA	1.02 (0.90 to 1.10)	0.70 to 1.36	1.00 (0.88 to 1.08)	0.68 to 1.34	p<0.0001
Sedentary	8.90 (8.63 to 9.22)	7.77 to 9.88	8.69 (8.46 to 8.92)	7.57 to 9.81	p<0.0001

Table 13: Paired Wilcoxon tests comparing the ActiGraph® GT3X+ Vertical axis (VT) estimates of physical activity and sedentary behaviour (hours/day) between automated and manual sleep removal methods.

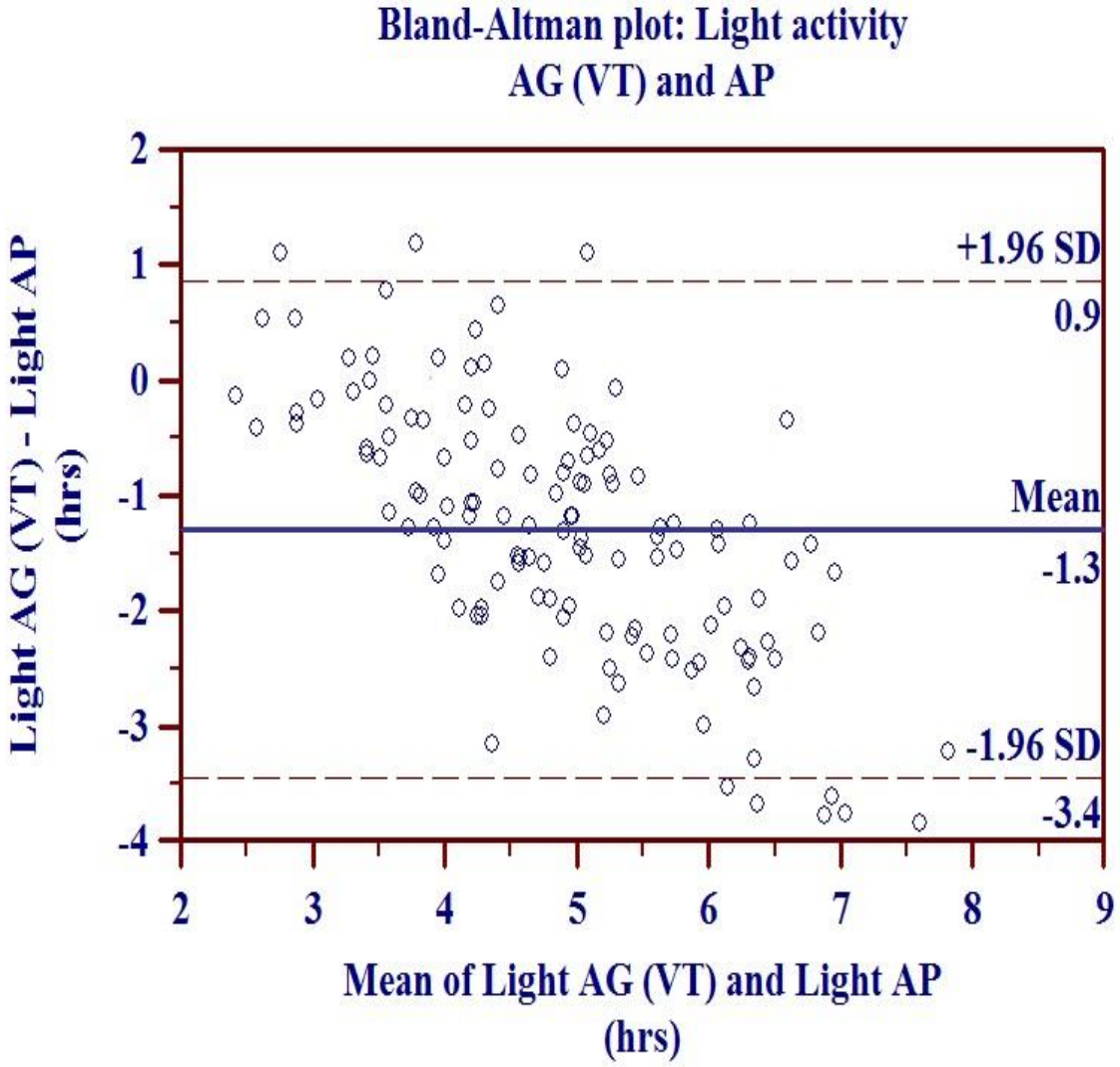
Activity type	ActiGraph® GT3X+ (Auto) **Median (95% CI) hrs**	Interquartile Range (AG)	ActiGraph® GT3X+ (sleep removed) **Median (95% CI) hrs**	Interquartile Range (AP)	Wilcoxon test p-value (α=0.05)
Light Activity	4.27 (4.04 to 4.45)	3.63 to 5.00	4.18 (3.95 to 4.34)	3.50 to 4.90	p<0.0001
Moderate activity	0.55 (0.51 to 0.61)	0.34 to 0.78	0.54 (0.50 to 0.58)	0.33 to 0.78	p<0.0001
MVPA	0.65 (0.57 to 0.71)	0.40 to 0.89	0.63 (0.57 to 0.68)	0.40 to 0.88	p<0.0001
Sedentary	8.41 (8.18 to 8.61)	7.50 to 9.34	8.50 (8.28 to 8.68)	7.49 to 9.45	p=0.0004

Table 14: Absolute reliability of physical activity and sedentary behaviour (hours/day) for the ActiGraph® GT3X+ VM, VT and activPAL3®. ICCs reported for the percent of wear-time for each behaviour category.

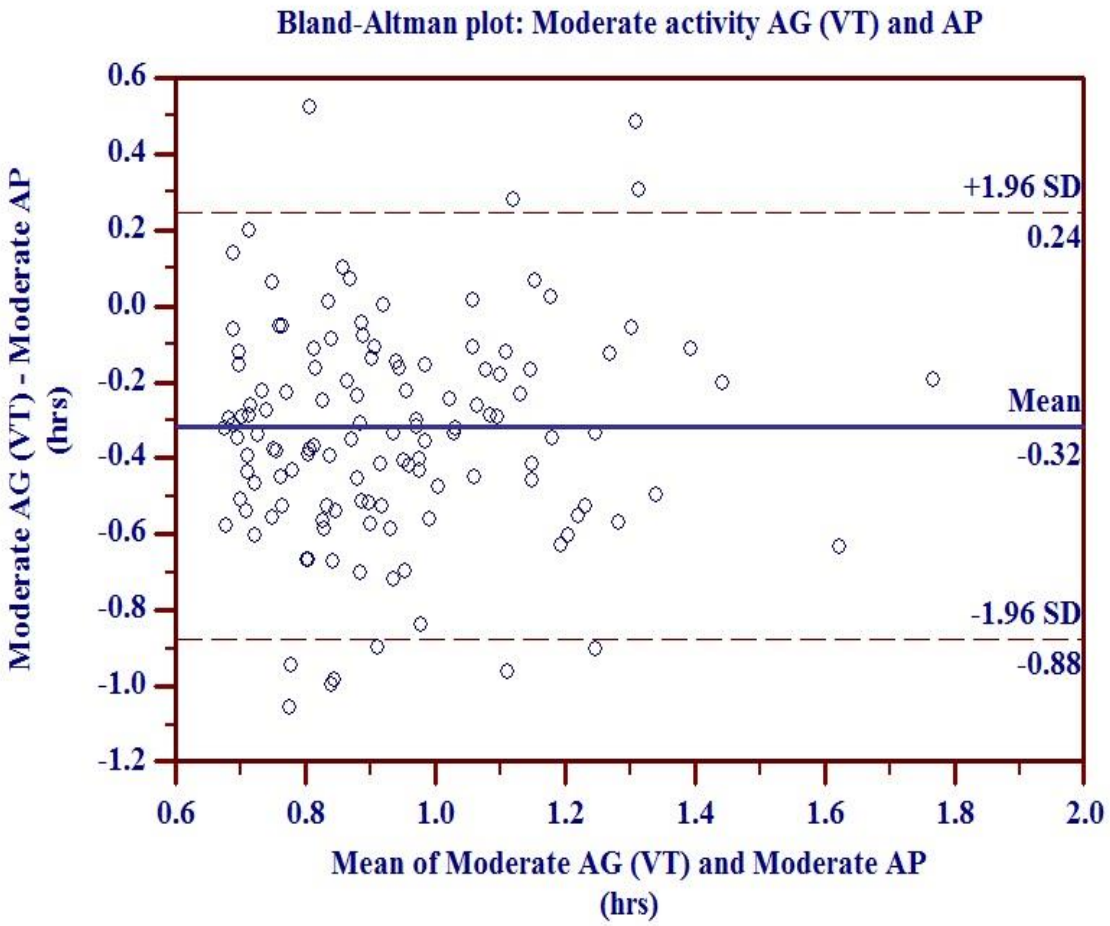
Activity type	Vector Magnitude ICC (95% CI) (% time)	Vertical VT axis ICC (95% CI) (% time)	activPAL3® ICC (95% CI) (% time)
Light Activity	0.87	0.84	0.89
	(0.73 to 0.94)	(0.67 to 0.93)	(0.76 to 0.95)
Moderate activity	0.88	0.66	0.82
	(0.75 to 0.95)	(0.30 to 0.84)	(0.63 to 0.92)
Vigorous	0.87	0.89	N/A
	(0.72 to 0.94)	(0.77 to 0.95)	
MVPA	0.88	0.67	0.82
	(0.75 to 0.94)	(0.31 to 0.84)	(0.63 to 0.92)
Sedentary behaviour	0.91	0.93	0.90
	(0.81 to 0.96)	(0.86 to 0.97)	(0.80 to 0.95)

Figure 11: Bland-Altman plots assessing agreement between the ActiGraph® GT3X+ VT and the activPAL3® for physical activity and sedentary behaviour (hours/day).

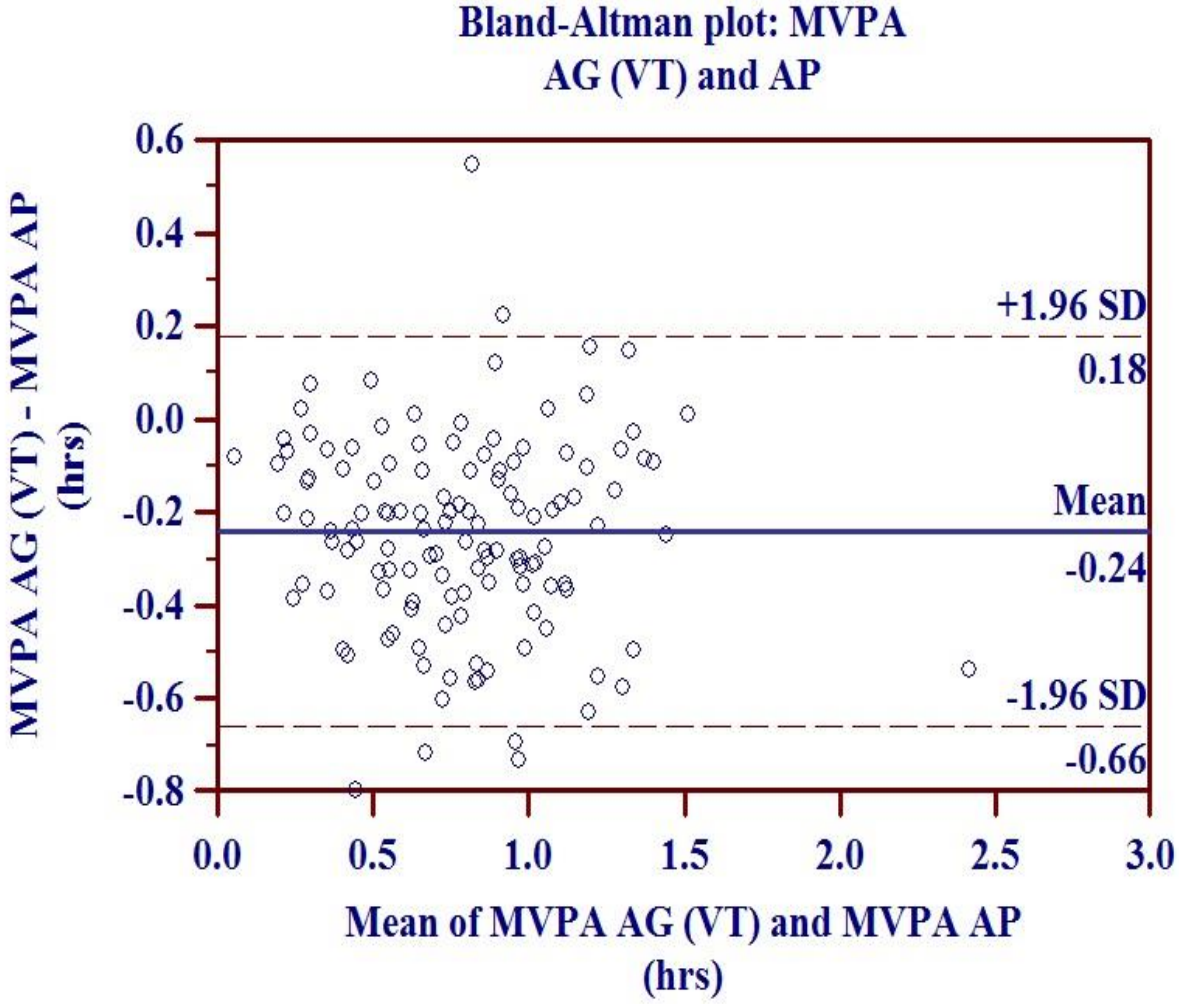
a) Light activity



b) Moderate activity



c) MVPA


Bland-Altman plot: MVPA
AG (VT) and AP
MVPA AG (VT) - MVPA AP (hrs)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
+1.96 SD
0.18
Mean
-0.24
-1.96 SD
-0.66
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Mean of MVPA AG (VT) and MVPA AP (hrs)

d) Sedentary behaviour

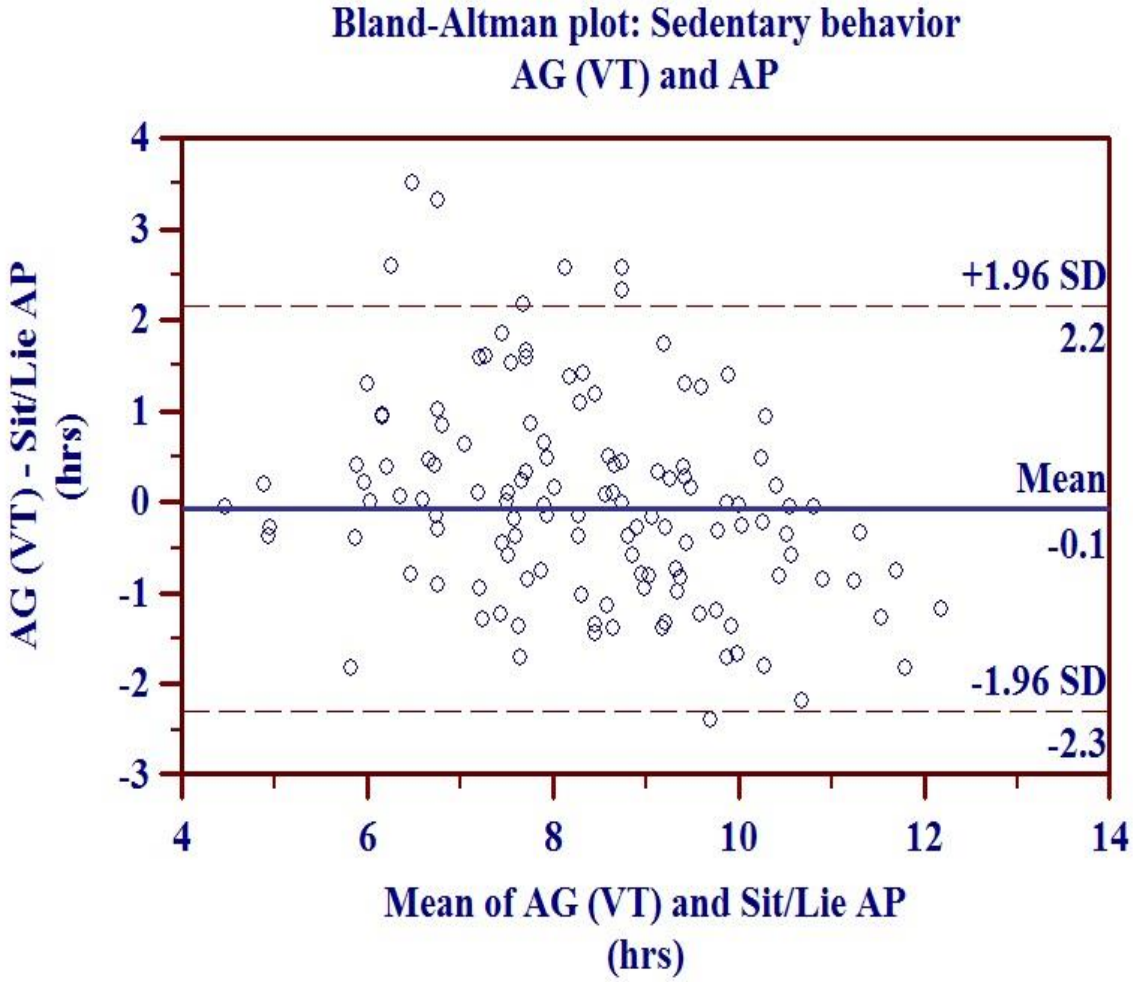
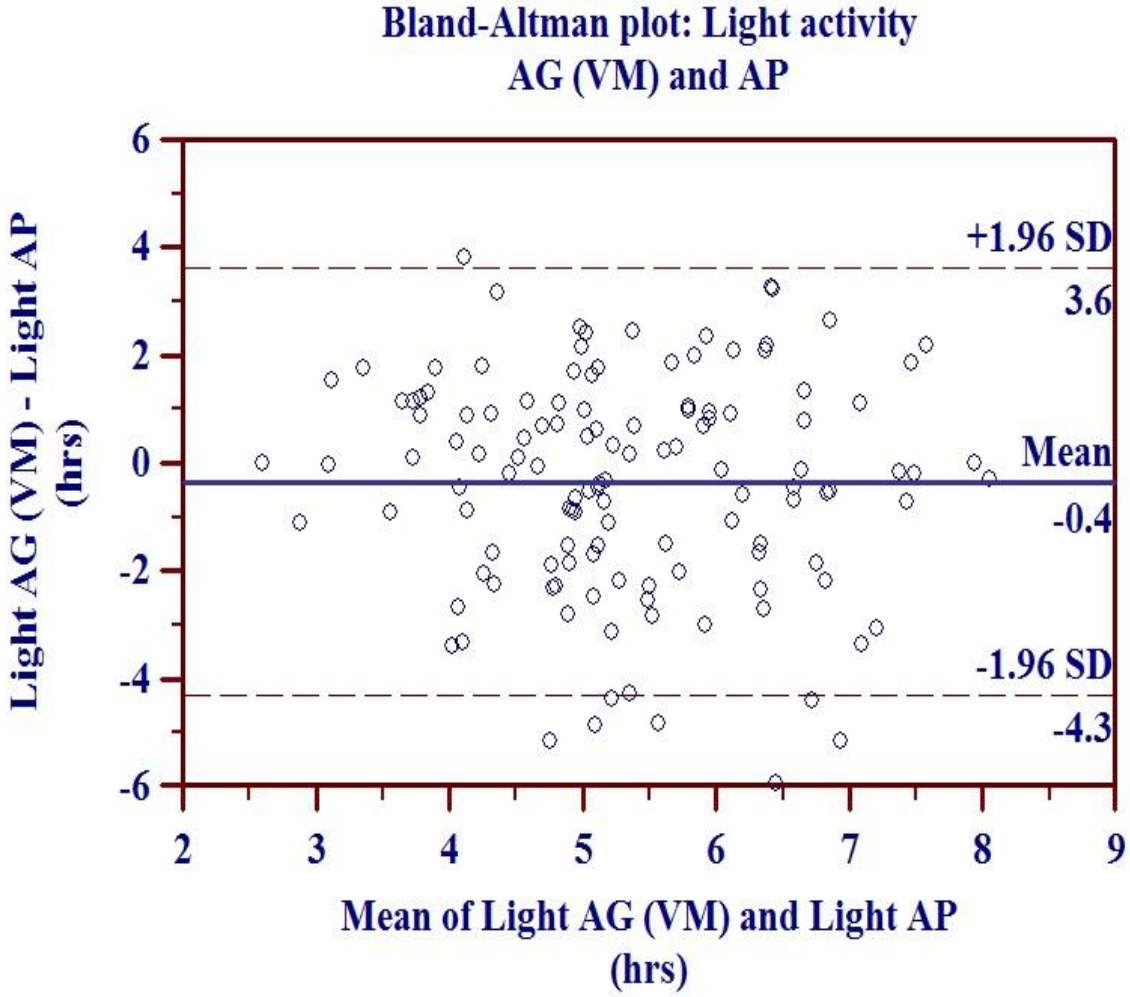
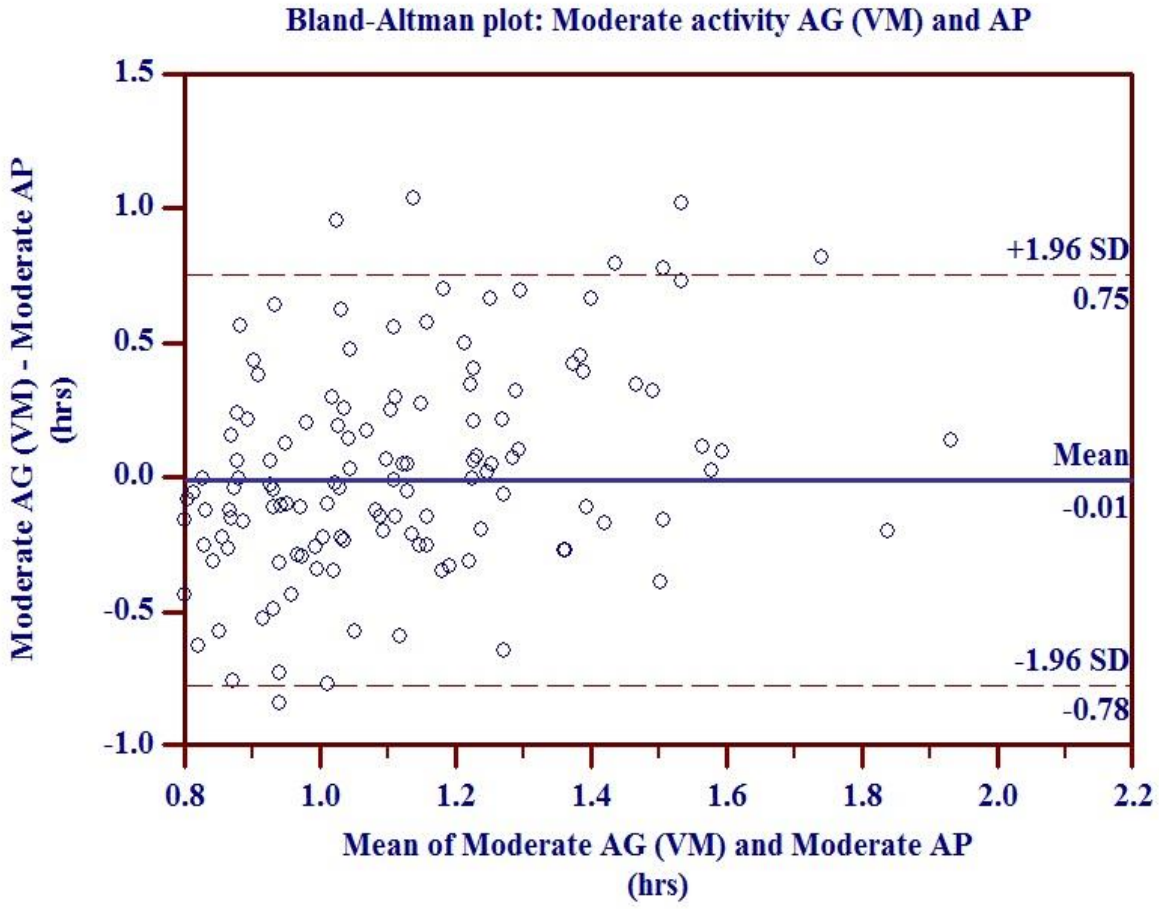


Figure 12: Bland-Altman plots assessing agreement between ActiGraph® GT3X+ VM and activPAL3® for physical activity and sedentary behaviour (hours/day).

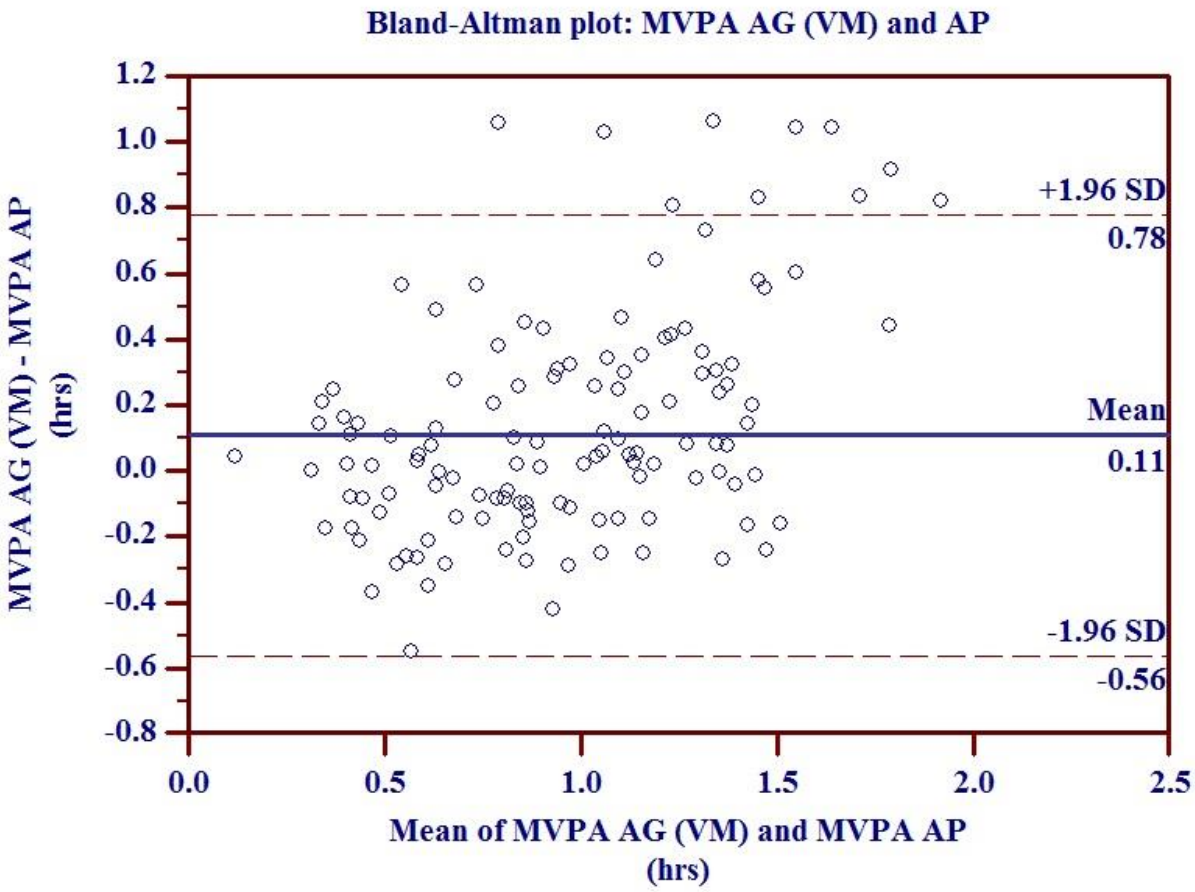
a) Light activity



b) Moderate activity



c) MVPA


Bland-Altman plot: MVPA AG (VM) and AP
MVPA AG (VM) - MVPA AP (hrs)
Mean of MVPA AG (VM) and MVPA AP (hrs)
+1.96 SD
0.78
Mean
0.11
-1.96 SD
-0.56
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0.0
0.5
1.0
1.5
2.0
2.5

d) Sedentary behaviour

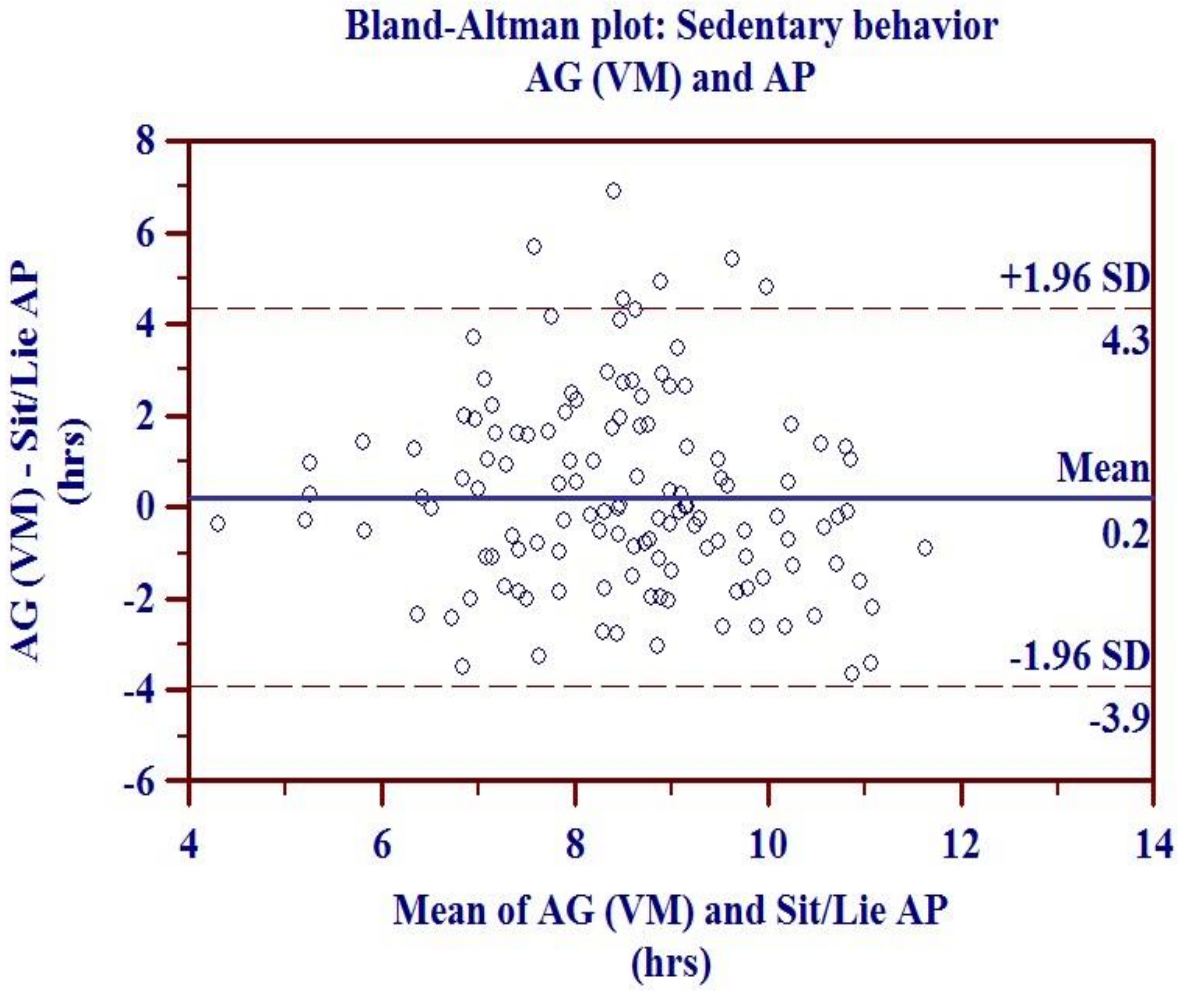
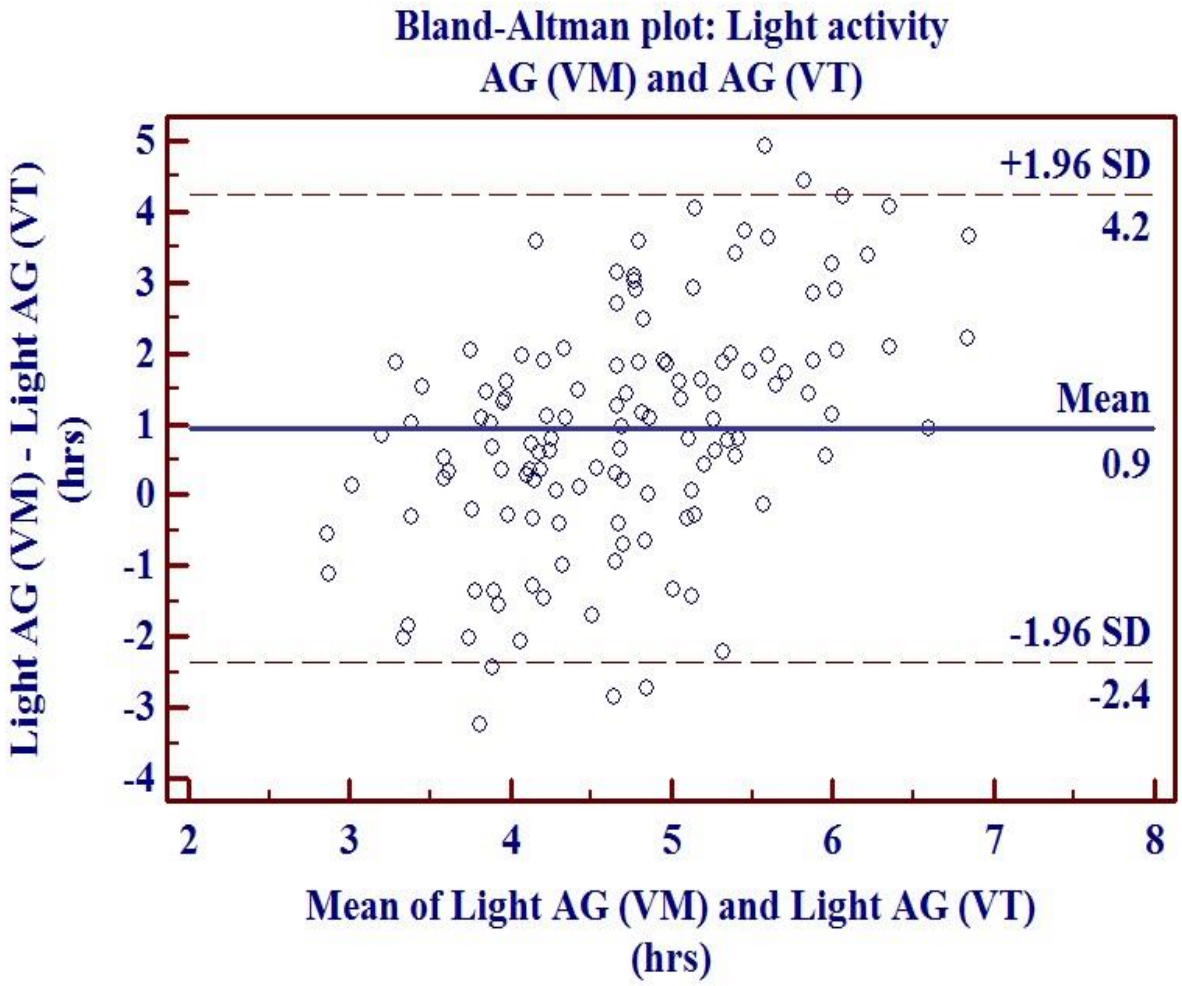
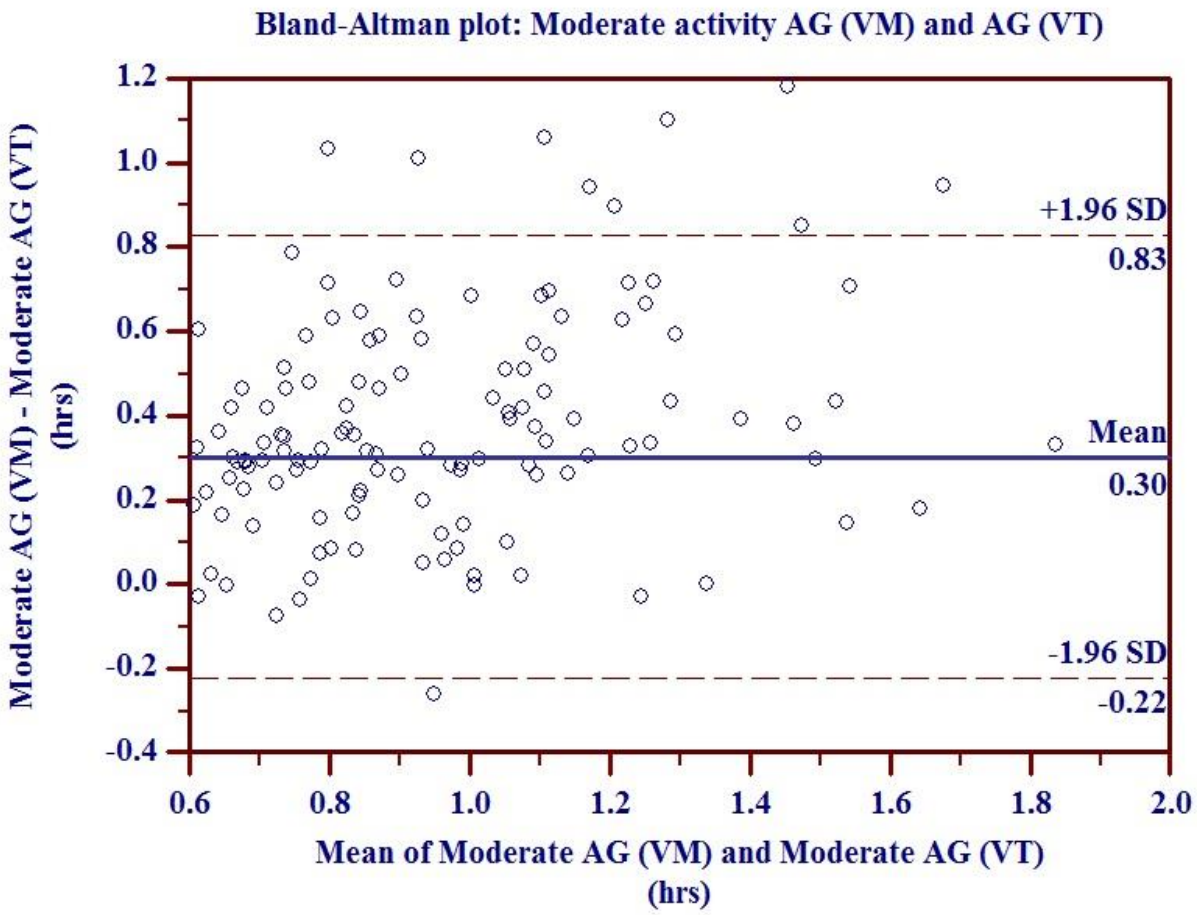


Figure 13: Bland-Altman plots assessing agreement between the ActiGraph® GT3X+ VM and VT for physical activity and sedentary behaviour (hours/day).

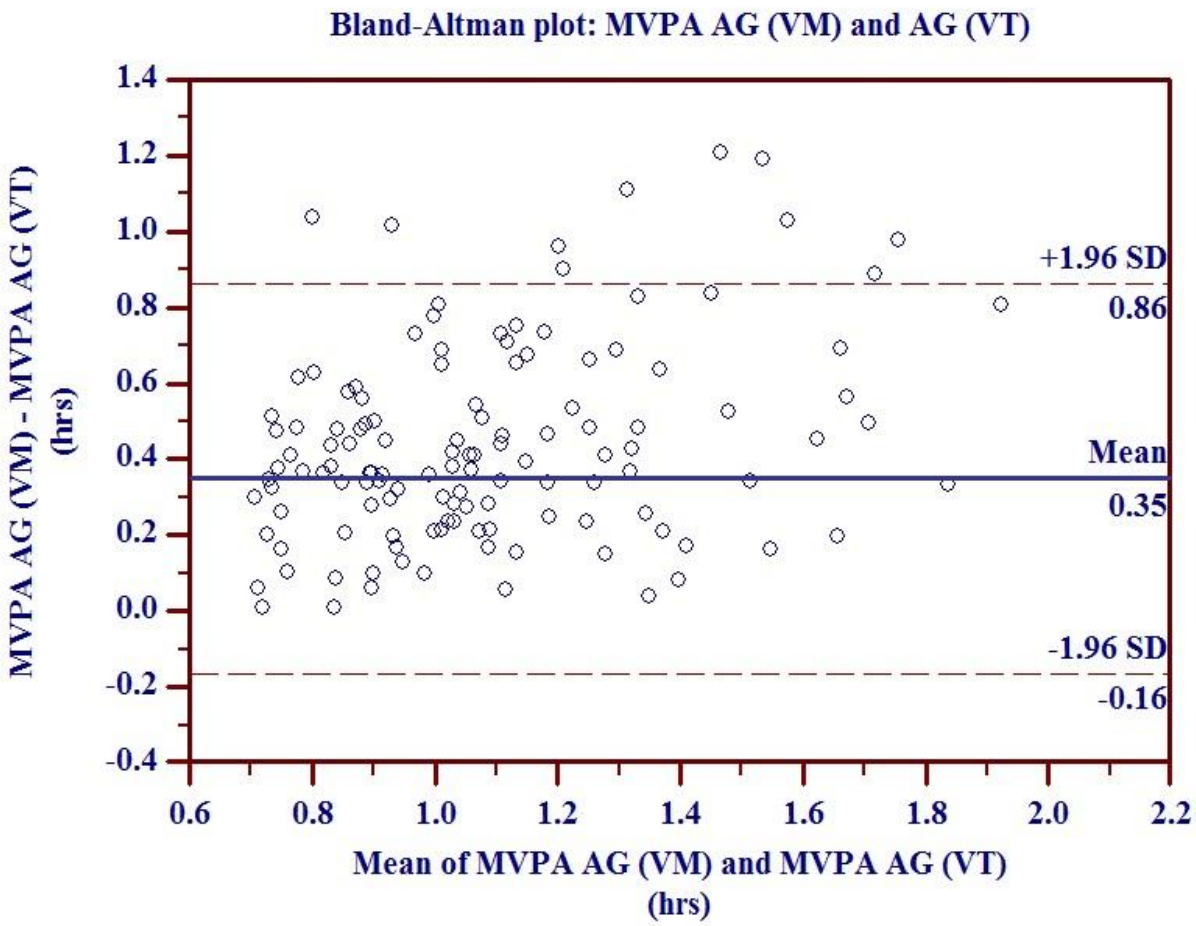
a) Light activity



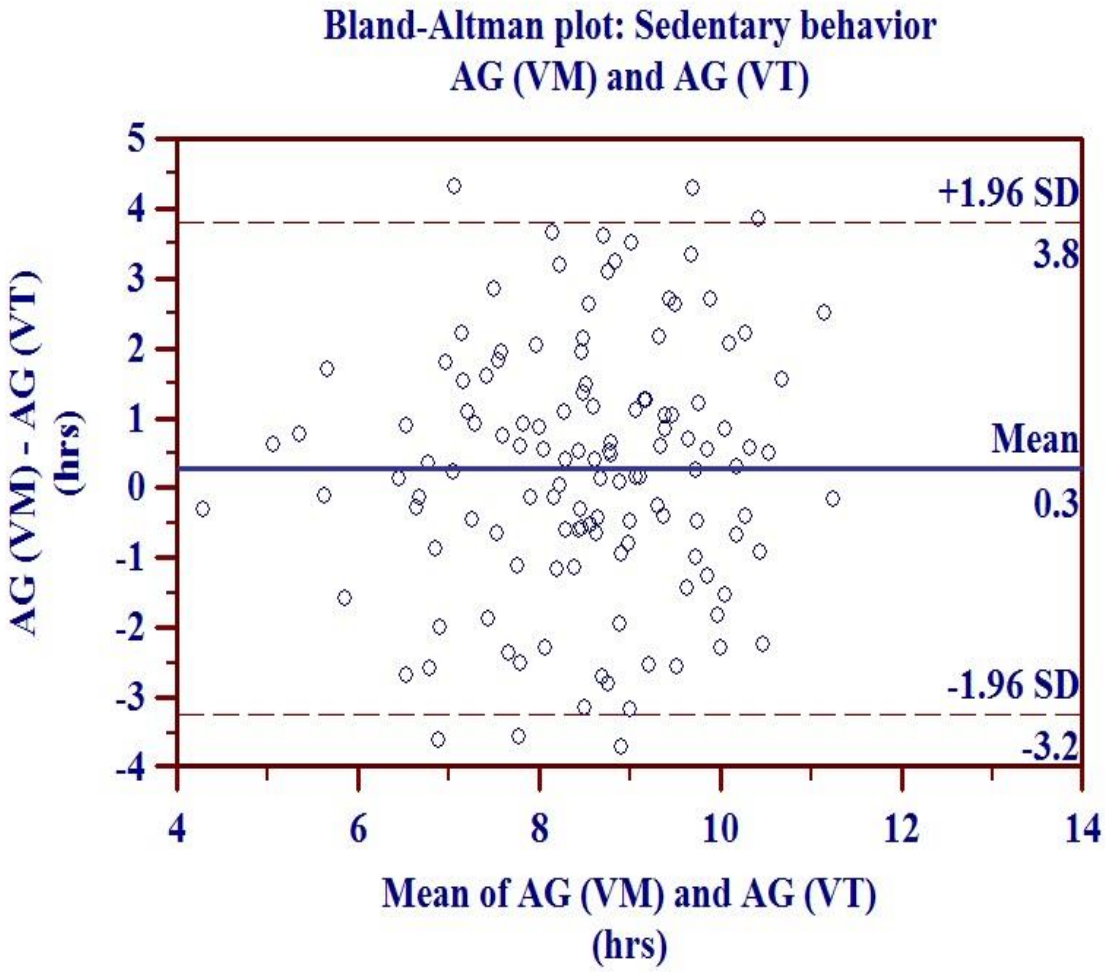
b) Moderate activity



c) MVPA


Bland-Altman plot: MVPA AG (VM) and AG (VT)
MVPA AG (VM) - MVPA AG (VT) (hrs)
Mean of MVPA AG (VM) and MVPA AG (VT) (hrs)
+1.96 SD
0.86
Mean
0.35
-1.96 SD
-0.16
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2

d) Sedentary behaviour



Chapter Five: **DISCUSSION**

5.1 Overview of main findings

The purpose of this study was to assess the convergent validity and test-retest reliability for estimates of physical activity and sedentary behaviour between the ActiGraph®, including VT and VM methods, and the activPAL3®. Another objective was to compare ActiGraph® VM and VT estimates of physical activity and sedentary behaviour using automatic versus manual wear-time estimation methods. When comparing the ActiGraph® VT to the activPAL3® for total time in physical activity, statistically significant differences occurred for all intensities of light, moderate and MVPA ($p<0.001$). Specifically, the median aggregate time spent in each activity intensity detected by the ActiGraph® VT was not the same as the median aggregate time for each activity intensity detected by the activPAL3® device. Similar to the VT axis, the ActiGraph® VM recorded statistically significant differences for time in physical activity intensities of light and MVPA, with the exception of moderate activity when compared to the activPAL3®. No statistically significant differences occurred between the ActiGraph® VT and the activPAL3® as well as between the ActiGraph® VM and activPAL3® for total aggregate time in sedentary behaviour. When comparing the ActiGraph® VT and VM methods of measurement for aggregate time in physical activity, statistically significant differences were found for each intensity of physical activity including light, moderate and MVPA. Despite the fact that the two different methods of detecting sedentary time by the ActiGraph® VT (<100 CPM) and VM (inclinometer) were not statistically different from the activPAL3®, the two methods were statistically significantly different from each other.

Using only ActiGraph® data, automatic estimation of physical activity and sedentary behaviour was statistically significantly different compared to manual sleep removal for both methods of VM and VT. Despite the statistically significant difference between automatic and manual wear-time estimation methods, the mean difference (hours/day) was small for total aggregate time in each activity intensity and sedentary behaviour. Bland-Altman plots assessing agreement between methods of measurement at the individual level show that the limits of agreement for all physical activity and sedentary behaviour estimates between ActiGraph® VT, VM and activPAL3® are too wide, indicating these two devices cannot be used interchangeably.

The test-retest reliability (ICC) was high and consistent across all physical activity and sedentary behaviour estimates for the ActiGraph® VT, VM and the activPAL3® with the exception of moderate and MVPA for the ActiGraph® VT which showed low to moderate reliability. These results show low behavioural variation between weekly recordings and indicate that participant recordings of at least one week is capturing habitual physical activity and sedentary behaviour patterns, at least for the short term.

5.2 ActiGraph® GT3X+ VT and activPAL3®

When comparing estimates of physical activity and sedentary behaviour for the ActiGraph® VT with the activPAL® device in this sample of older post-menopausal women, it is evident that for each physical activity intensity reported, the two methods are significantly different ($p<0.001$). Despite this statistically significant difference in all physical activity intensities between the two methods of measurement, the mean difference between methods in estimated time (hours/day) spent in each physical activity intensity is quite small. The largest

mean difference occured in light intensity activity (1.3 hrs) and becomes smaller with moderate activity (0.32 hrs) and MVPA (0.24 hrs). With the majority of activity time being spent in light activity, it is expected that the largest difference would occur in this behaviour between these two methods of measurement. With this study population, less time was spent in moderate and MVPA activity which resulted in smaller mean differences. Provided with this information, it must be determined whether or not these differences in estimated physical activity behaviours are acceptable between these two methods and the statistical significance is a result of a large sample size with small variance or if these differences in reported physical activity intensities are, in fact, too large between methods of measurement. A more in-depth analysis assessing the agreement between these two methods of measurement can provide clues as to whether or not these two methods can be used interchangeably to measure physical activity. For light intensity activity, a noticeable pattern appears since the ActiGraph® VT reports higher estimates compared to the activPAL3® when light activity is low. When light activity increases, the activPAL3® reports higher estimates compared to that of the ActiGraph® VT. This tendency is particularly pronounced at these higher estimates of light activity. In this sample, the ActiGraph® VT can potentially record between 3.4 hours less light activity compared to the activPAL3® and 0.9 hours more. The agreement between these two methods when measuring light activity demonstrates a significant bias despite the relatively low mean difference in estimated time spent in light activity. When assessing agreement between methods for moderate activity, this tendency is absent. However, the activPAL3® does tend to report higher values compared to the ActiGraph® VT for moderate activity similar to light activity. The agreement between methods for MVPA is very similar to moderate activity, with the activPAL3® reporting

more MVPA compared to the ActiGraph® VT. Compared to the activPAL3®, the ActiGraph® VT can potentially record 0.88 hours less or 0.24 hours more of moderate activity and 0.66 hours less or 0.18 hours more of MVPA. Despite the seemingly small limits of agreement, moderate activity and MVPA are behaviours that do not occur frequently throughout the waking day, with recommended guidelines of 150 minutes per week or 30 minutes a day for five days per week (16). Therefore, with the potential for the ActiGraph® VT to report slightly under an hour less moderate activity or MVPA compared to the activPAL3®, this underreporting can be considered too large a margin of error to permit the use of these two objective assessment methods interchangeably.

An important behaviour estimated by these two methods is sedentary behaviour. The majority of the waking day is spent in sedentary behaviour as determined from these two devices. The mean difference between both methods is small (0.1 hours) and no statistically significant difference was found between the two devices ($p=0.27$). A slight pattern appears when assessing agreement between the ActiGraph® VT (<100CPM) and activPAL® (sit/lie), since the activPAL® consistently reports higher estimated time in sedentary behaviour when time in sedentary behaviour is high, approximately >10 hours a day. The limits of agreement are approximately equal, with ActiGraph® VT potentially reporting 2.3 hours less or 2.2 hours more of sedentary behaviour. These limits of agreement are wide and with the potential to over- or underreport more than two hours of sedentary time using one method may have a noticeable impact on the accurate assessment of sedentary behaviour. From previous research, the estimates of sedentary behaviour from the activPAL® device may be considered the gold standard (6, 7, 65, 67). With this prior evidence in mind, it is possible that the ActiGraph® VT is

biased to over-estimating sedentary behaviour when time in sedentary behaviour is low and under-estimating sedentary behaviour when time in sedentary behaviour is high.

5.3 ActiGraph® GT3X+ VM and activPAL3®

When comparing estimates of physical activity between the ActiGraph® VM and activPAL3®, light intensity activity ($p=0.05$) and MVPA ($p=0.0001$) were statistically significantly different while no reported difference existed for moderate activity ($p=0.15$). Despite the statistically significant difference between reported estimates for light activity and MVPA, the mean difference is small across all physical activity categories. The activPAL3® device did not record any time spent in vigorous activity. Thus, the estimated time spent in MVPA for the activPAL3® is moderate activity alone and when compared to the ActiGraph® VM, which recorded a very small amount of vigorous activity, it is expected that the estimated time in MPVA would be higher and there would be a statistically significant difference between the two methods. Since total time in each physical activity category was similar between both methods of measurement, a more in-depth analysis assessing the agreement between devices can demonstrate patterns in the way each method is estimating physical activity. For light intensity activity, it is clear that a large range of recorded activity exists between approximately three to eight hours a day. No systematic bias is apparent, however, it appears that the limits of agreement are wide spanning across the range of time spent in light activity. The ActiGraph® VM can potentially record 4.3 hours less to 3.6 hours more than the activPAL3®. These limits of agreement are too wide to use one method accurately over the other to estimate light activity, especially when this degree of under- or over-reporting of one device occurs throughout the

duration of the mean estimated time in light intensity activity. For moderate activity, a slight pattern appears as the ActiGraph® VM tends to over-report compared to the activPAL3® when the mean estimated time in moderate activity is high. Despite the very low mean difference or bias of only 0.01 hours between the two methods, the limits of agreement demonstrate that the ActiGraph® VM can potentially record 0.78 hours less to 0.75 hours more compared to the activPAL3®. Considering that typical patterns of time spent in moderate activity on any given day is low, around a half hour to an hour per day, these limits of agreement are likely too large to use one method over the other to estimate time spent in moderate activity. The same pattern appears for MVPA, since the ActiGraph® VM reports higher values compared to activPAL3® when the estimated mean time in MVPA is high. Despite the small mean difference, similar to all other physical activity categories, the limits of agreement are wide with the potential for the ActiGraph® VM to report 0.56 hours less to 0.78 hours more than the activPAL3® device. With these limits of agreement being greater than half an hour per day of MVPA, the two methods may not be used interchangeably to estimate MVPA.

A critical behaviour that needs to be measured similarly by these two methods is sedentary behaviour. Both of these methods use an inclinometer to estimate the combined time spent in a seated or lying position as detected by the monitors. No statistically significant difference was detected by the two methods for total mean time (hours/day) spent in sedentary behaviour ($p=0.48$). When assessing the agreement between methods, a pattern appears with the ActiGraph® VM estimates of sedentary behaviour being higher compared to the activPAL3® when the estimated mean time in sedentary behaviour is around the average for the entire sample, approximately eight to ten hours per day. Subsequently, the ActiGraph® VM reports

less time in sedentary behaviour compared to the activPAL3® when the estimated mean time in sedentary behaviour is high. Despite the small mean difference between methods, the limits of agreement are wide, with the potential for the ActiGraph® VM to record 3.9 hours less to 4.3 hours more time in sedentary behaviour compared to the activPAL3® device. These limits of agreement are too wide to estimate sedentary behaviour using one device over the other.

5.4 ActiGraph® GT3X+ VT and VM

When comparing estimates of physical activity between these two methods of measurement, statistically significant differences were found across all physical activity intensities ($p<0.0001$). Again, the mean difference appears small when comparing the aggregate mean time per day for each physical activity category, despite the statistical significance. When assessing the agreement between methods, visible patterns appear for all physical activity categories. For light intensity activity, it is clear that the ActiGraph® VM reports less time in light activity compared to VT when mean time in light activity is low. Furthermore, VM clearly reports more time in light activity compared to VT when mean time in light activity is high. The limits of agreement are wide with the potential for VM to report 2.4 hours less to 4.2 hours more compared to VT. When estimating light intensity activity, these limits are likely too wide to use one method over the other. The same pattern appears for moderate activity and MVPA, as the ActiGraph® VM underreports time in moderate intensity and MVPA compared to VT when mean time in both physical activity intensities are low and overestimates time in moderate activity and MVPA compared to VT when mean time in both physical activity intensities are high. The limits of agreement are wide with the potential for VM to report 0.22 hours less to

0.83 hours more moderate activity compared to VT and 0.16 hours less to 0.86 hours more of MVPA compared to VT. These limits of agreement for moderate activity and MVPA are too wide to use one device over the other.

A statistically significant difference was found between the two methods of measurement for the estimation of sedentary behaviour ($p=0.03$). The mean difference was small despite the statistical significance when comparing total mean time (hours/day) of sedentary behaviour estimates for the entire sample. No visible patterns are apparent when assessing the agreement between methods of measurement for estimation of sedentary behaviour. The limits of agreement are wide, with the potential for ActiGraph® VM to report 3.2 hours less or 3.8 hours more time in sedentary behaviour compared to VT. These limits of agreement suggest the two devices cannot be used interchangeably to estimate sedentary behaviour.

5.5 Behavioural Variation

The test-retest reliability was high (>0.8) for each method of measurement across all physical activity intensities and sedentary behaviour, with the exception of moderate activity and MVPA for the ActiGraph® VT which demonstrated moderate reliability (>0.6). Using the average time per day for each behaviour category and expressing that value as a percent of total wear-time may increase the ICC for each method of measurement. Using the average time per day across a week long recording indicates behavioural variation from week-to-week. The results from this study show low behavioural variation and that week long recordings for each device and method of measurement is capturing habitual physical activity and sedentary behaviour patterns.

5.6 Estimating Wear-time

When comparing the total mean time (hours/day) in physical activity and sedentary behaviour between manual and automatic methods of estimating wear-time for both the ActiGraph® VM and VT, statistically significant differences were found for all physical activity intensities and sedentary behaviour. Similar to the comparison with the activPAL® device, the mean difference for all physical activity categories and sedentary behaviour between automatic and manual methods of estimation were small. For both methods of measurement, VM and VT, the automatic approach estimated slightly more wear-time compared to manual sleep removal. This result is likely attributable to the idea that participants may estimate and record in their diary log the time they put the monitor on and off, leading to wear-time estimation errors. This recall error, in estimating the exact on and off times, has resulted in differences in wear-time estimation between the automatic and manual methods. The automatic approach takes into account each minute containing count data, which on some occasions extends past the time that a participant records the stop time, resulting in greater estimated wear-time. Since the mean difference for each behaviour category is so small between both methods of automatic and manual wear-time estimation, it can be reasoned that this automatic approach is a valid method of estimating physical activity and sedentary behaviour despite the statistically significant differences in physical activity and sedentary behaviour estimates. For the ActiGraph® VM, two potential behaviours of concern, when comparing automatic and manual wear-time estimation, are sedentary behaviour and light intensity activity. These two behaviours had the largest mean difference (>0.09) compared to all other behaviours of VM and VT. It appears that the automatic approach is overestimating sedentary behaviour and underestimating light activity compared to

the manual method. One potential reason for this bias may be the recall error in estimating when the devices were removed in the diary log. If the device records slightly more wear-time past the participant's recorded time the device was removed in the evening, this extra time is likely recorded by the inclinometer as sitting or lying (sedentary behaviour). Thus, the automatic approach would overestimate sedentary behaviour compared to the manual approach. As a result, less light activity would be detected by the automatic approach since the formula for light activity takes into account the amount of sedentary behaviour (0-260 CPM – sedentary behaviour). This bias does not exist for VT, since sedentary behaviour and light activity are detected solely by count data, and light activity is not partially determined by time spent in sedentary behaviour.

5.7 Previous Research

Seven studies have compared estimates of sedentary behaviour between the ActiGraph® VT validated cut-points and the uni-axial activPAL® device. The ActiGraph® models used in these studies include the GT1M, GT3X and GT3X+ (51-56, 58).Two studies found statistically significant differences in total time in sedentary behaviour at the group level with p-values <0.001 (54, 55). Hart and colleagues (2011) used the previously validated ActiGraph® cut-count point of < 100 CPM (AG100 CPM) in a small sample of 32 adults (54). Martin and colleagues (2011) used a sample of pre-school aged children and used a separate sedentary cut-point (<1100 CPM) for this age group that has been previously validated (55). Two other studies assessed sedentary behaviour using the AG VT cut-point of less than 100 CPM, but also assessed sedentary behaviour using multiple other VT cut-points and compared to the activPAL® (56,

58). Kozey-Keadle and colleagues (2010) found that the activPAL® and AG100 CPM underestimated sedentary time compared to DO by 2.8% and 4.9%, respectively (56). This study also suggested that the ActiGraph® VT cut-point for sedentary behaviour of <150 CPM (AG150 CPM) performed better compared to the activPAL® with the smallest bias of 1.8% (56). Ridgers and colleagues (2012) showed that the AG100 CPM, to define sedentary time, had the smallest mean bias during school hours in adolescents compared to the activPAL® (58). This study by Ridgers et al (2012) also found that the smallest mean bias for ActiGraph® VT sedentary cut-points compared to the activPAL® changed depending on whether or not children were in class (AG150) or on break (AG50) (58). In our study we collected information on sedentary behaviour from the VT axis using the previously validated AG100 CPM. Contrary to previous results, we found no statistically significant differences comparing the AG100 CPM to the activPAL® device at the group level ($p=0.27$). Our results may not be comparable to Martin and colleagues (2011) who assessed sedentary behaviour on pre-school children using cut-points specific to that population (55). However, it is unclear why our results are different from Hart and colleagues (2011), since free-living conditions were used in each study with adult participants wearing both devices concurrently.

Two studies compared physical activity assessments made with the ActiGraph® VT and uni-axial activPAL® (53, 54). Hart and colleagues (2011) found significant differences between methods for time in walking activity ($p<0.001$), the only comparable category of physical activity between the two devices in this study (54). Dowd and colleagues (2012) showed a strong positive relationship between the count function of the ActiGraph® and activPAL® ($r=0.96$ $p<0.01$) demonstrating high concurrent validity between devices (53). Our study has not

specifically reported on walking activity or correlations between count function of either device. Furthermore, we detected light intensity activity using VT cut-points and light walking activity would fall within this category. Similar to Hart and colleagues (2011), our study found a statistically significant difference between the ActiGraph® VT and activPAL3® for total time in light activity ($p<0.001$). Previous studies have not compared or reported estimates of moderate or MVPA activity between the ActiGraph® VT and activPAL® because the uni-axial activPAL® used in these studies could not delineate time in these types of activities. Furthermore, we used the tri-axial activPAL3® for all comparisons of physical activity with the ActiGraph® VT with no comparison using the uni-axial activPAL®.

Two studies have assessed agreement between the ActiGraph® VT and activPAL® using Bland-Altman plots comparing individual time in physical activity and sedentary behaviour (54, 55). Hart and colleagues (2011) found no systematic biases between methods for all behaviour categories, except for activPAL® and BAR for standing, activPAL® and ActiGraph® for walking, as well as for ActiGraph® and BAR for walking (54). Hart and colleagues (2011) found that despite the fact that the ActiGraph® recorded more time walking, when estimated time in walking activity was low, the activPAL® recorded higher values compared to the ActiGraph® and when time in walking activity was high the ActiGraph® recorded more time compared to the activPAL®. Our study also found the ActiGraph® reported more time in light activity compared to the activPAL®, however, the Bland-Altman plot demonstrates that when time in light activity is low, the ActiGraph® recorded more time compared to the activPAL® and when time in light activity was high, the ActiGraph® recorded less time compared to activPAL®. This same pattern was found for time in sedentary behaviour. This finding is contrary to what Hart and colleagues

(2011) have demonstrated with respect to the systematic bias found between methods for walking activity (54). Our study found no systematic biases between methods for time in moderate and MVPA activity. Similar to the study by Hart et al (2011), the limits of agreement between methods for comparable behaviours are wide, indicating that the devices may not be used interchangeably. Martin and colleagues (2011) used Bland-Altman plots to assess agreement between ActiGraph® and activPAL® for percent time in sedentary behaviour in pre-school children (55). This study found that agreement at the individual level was poor, with mean difference (limits of agreement) of -4.3% (-14.0% to 5.0%). Martin and colleagues (2011) noted that at the group level, estimated time in sedentary behaviour was similar despite the statistically significant difference ($p<0.001$) (55). This finding is similar to the results in our study demonstrating that at the group level, time in sedentary behaviour between methods is small ($p<0.27$), however, agreement between methods at the individual level demonstrates that limits of agreement are too wide to use both devices interchangeably.

Only one study used the ActiGraph® GT3X+ and assessed sedentary behaviour using the inclinometer function (52). This study compared the inclinometer function of both the activPAL®, ActiGraph® and a device known as the sitting pad, which attaches to a chair and detects time seated and sit-to-stand transitions, and compared to DO using a video camera. Although no comparison was made between the ActiGraph® and activPAL®, the study found that the ActiGraph® GT3X+ inclinometer performed poorly compared to DO, while the activPAL® and sitting pad demonstrated high levels of agreement compared to DO (52). Our study directly compared the estimated time in sedentary behaviour using both devices' inclinometer function and found no statistically significant difference between group means

(p=0.48). The level of agreement at the individual level shows no systematic bias between methods but the limits of agreement are too wide to use either method interchangeably. No study has previously compared ActiGraph® VM estimates of physical activity to the activPAL® device. Our study shows statistically significant differences for group means between the ActiGraph® VM and activPAL3® across all physical activity intensities ($p<0.001$) with the exception of moderate activity ($p=0.15$). Furthermore, no previous study has compared ActiGraph® VM and VT estimates of physical activity and sedentary behaviour on the same sample. Our study found statistically significant differences between group means across all behaviours of physical activity and sedentary behaviour between VM and VT methods of measurement.

Three studies have estimated the inter-instrument reliability of the ActiGraph® device using VT cut-points on the GT1M, GT3X and 7164 models (60, 62, 63). Two of these studies used similar free-living conditions having participants wear multiple monitors for a 24-hour period (60, 62). These studies found similar results with high inter-instrument reliability for moderate-to-vigorous physical activity. One of the limitations of the study by McClain and colleagues (2007) was that inter-instrument reliability was tested with only two devices for 10 subjects while Vanhelst and colleagues (2012) indicated a high inter-instrument reliability of the ActiGraph® in moderate- to high-intensity physical activity using eight devices per 15 subjects in free-living conditions (60, 62). One study assessed inter-instrument reliability using both VT and VM cut-points in a laboratory setting (63). This study estimated inter-instrument reliability to be high for individual x, y and z axes as well as for VM and noted no advantage to using VM over VT cut-points. This study, however, used eight monitors on only one adult male subject in a

laboratory condition. Only one study has assessed the intra-device reliability in a free-living condition (59). Sirard and colleagues used a large sample of 143 adults who wore the same monitor for two seven day periods, one to four weeks apart (59). This study used multiple automatic wear-time algorithms to estimate physical activity and sedentary behaviour and found reliability (ICC) to be high for each, ranging from 0.70 to 0.90 with reliability being lowest for the most stringent algorithm used to estimate wear-time (59). This study estimated physical activity and sedentary behaviour as the mean time in minutes per day for each week worn. Sirard and colleagues provide evidence that accelerometer data collected for one week is obtaining a reliable assessment of the individual's habitual activity level, at least in the short term (80). Our study employed a similar design, having participants wear the same monitor for two one week monitoring periods one week apart. Our study used a smaller sample and calculated physical activity and sedentary behaviour in hours per day and expressed this time as a percent of total wear-time to correct for differences in wear-time between monitoring periods. Similar to Sirard et al., our study has estimated the reliability of a single device over week-to-week recordings (59). Our results are similar to Sirard and colleagues, with ICCs ranging from 0.67 to 0.91. Our study provides further evidence that accelerometer data recorded over one week is reliable in estimating habitual activity for use in epidemiologic studies.

The majority of studies assessing reliability using the activPAL® device have estimated the inter-instrument reliability of small samples in a laboratory setting (6, 7, 67). These studies have concluded that the activPAL® is valid and reliable measure of walking and posture detection. Each of these studies has used a laboratory-based design to assess the inter-instrument reliability in small convenient samples. Despite this, the consistency between studies

demonstrates that the uni-axial activPAL® has high inter-monitor reliability for activities of walking (stepping) and posture detection. Only one study has assessed the intra-device reliability in a free living-condition (65). Hinckson and colleagues had 56 children wear the activPAL® for 24 hour per day for a continuous period of two weeks. The results of this study show the activPAL® had moderate to low week-to-week reliability for habitual activity and postural allocation under free-living conditions in boys and girls (65). Our study results conflict with Hinckson and colleagues, since we found that the activPAL® had high intra-device reliability when estimating physical activity and sedentary behaviour from week-to-week. Our results are similar between activPAL® and ActiGraph® and offers evidence that these monitors provide reliable estimates of habitual physical activity and sedentary behaviour from those recordings of at least one week. Differences in sample population may have attributed to the discrepant results between our study and Hinckson et al, 2012 (65). Hinckson and colleagues used a larger sample of young children including boys and girls while our study sampled 29 post-menopausal women currently participating in an exercise intervention trial. The women in our study were to exercise for the same duration and intensity from one week to the next, potentially providing more stable estimates of physical activity. Our study also used the tri-axial activPAL3® compared to the uni-axial activPAL® used by Hinckson and colleagues (65). The estimation of sedentary time between the activPAL3® and activPAL® remains the same with use of an in-built inclinometer. Our study showed the test-retest reliability to be high (ICC 0.90) for estimated time in sedentary behaviour between weekly recordings compared to the low reliability found by Hinckson and colleagues for both weekday (ICC 0.45) and weekend (ICC 0.58) estimates of sedentary time in children using the same technology and same method of

estimating week-to-week variation of physical activity and sedentary behaviour using percent of total wear-time.

The most recently developed and validated algorithm by Choi and colleagues (2011) has improved the previous and most commonly used algorithm developed with the NHANES data (71). This new algorithm incorporates several changes for use on the ActiGraph® device, including an increase in the minimum duration of detecting a non-wear window from 60 minutes to 90 minutes. Our study has used the automatic wear-time processing parameters developed by Choi and colleagues (2011) (Table 3) (71). Using this pre-defined algorithm for the ActiGraph®, our study tested several different durations of non-wear windows and compared heat maps to diary log data in order to select the non-wear window which best classified true non-wear. It was determined that a non-wear window of 60 minutes most accurately classified non-wear as reported by diary log information (Figure 2). This finding may have occurred since participants were currently undergoing an intervention trial and may have removed the device less frequently and for shorter periods of time. In addition, data were screened to include those participant recordings that were most compliant, obtaining a minimum 10 hours of wear-time per day for at least 4 days. The use of a 60 minute non-wear window is contrary to findings from Choi and colleagues (2012) (69). Choi et al (2012) compared the performance of 90 versus 60 minute non-wear windows for the ActiGraph® device using both VM and VT cut-points. Choi et al. (2012) found that the 90 minute window performed better than the 60 minute window compared to true wearing status determined by dairy log records (69). Using a 90 minute window, the mean correct classification probability increased from 0.95 to 0.98 and from 0.96 to 0.98 for wrist worn VM cut-points and waist worn VT cut-points, respectively (69). We did not

perform any statistical tests comparing the performance of the 60 and 90 minute non-wear windows using the pre-defined algorithm developed by Choi and colleagues (2011) (71). Instead, we used the algorithm deemed to classify true non-periods accurately and compared estimates of wear-time, physical activity and sedentary behaviour to those estimated by a manual sleep removal only method via diary log information. Despite finding statistically significant differences between methods for total median time in all physical activity intensities and sedentary behaviour, the differences in reported estimates are small. Our automated algorithm approach appears to be a valid method for estimating wear-time, physical activity and sedentary behaviour in a population of older sedentary women. Although Choi and colleagues have provided evidence that the 90 minute non-wear window performs better than 60 minutes in a population of older adults, we recommend that for any large epidemiologic study that is automatically processing accelerometer data for a large number of files, that multiple non-wear windows are tested against a small sample in which true non-wearing status is known. This process will enable researchers to choose the algorithm that best suits the population under study.

5.8 Study strengths

This study's main strength is the simultaneous measurement of physical activity and sedentary behaviour using the most technologically recent and popular accelerometers. Additional strengths include the large sample size of women and the tightly controlled exercise intervention trial in which detailed activity monitor logs were recorded at the time that the devices were worn. Furthermore, estimation of physical activity and sedentary behaviour variables for each device used the most up-to-date methods from the previous literature to ensure

the accurate assessment of the behaviours under investigation. These methods included the most current methods for data reduction and estimation of the summary variables.

The measurement of habitual activity in a free-living condition over the course of a week-long recording is important for use in large-scale epidemiologic studies aiming to quantify time spent in various physical activity and sedentary behaviours objectively. By accurately measuring these behaviours over the course of a week, measurement bias is reduced and more accurate measures of association can be obtained.

Another strength of this study was the detailed collection of times the two devices were worn and not worn with diary logs. With this diary information, it was possible to estimate physical activity and sedentary behaviour both manually by removing sleep with log information and automatically by using an algorithm to estimate wear and non-wear periods. The comparison of automatic versus diary log non-wear removal is important in order to determine whether or not the two methods produce significantly different estimates of the behaviours in question and whether the automatic algorithm chosen was accurate for mass processing of participant files. The use of diary log information allowed more precise removal of all non-wear times for the reliability sub-study because of the smaller sample size. This study was able to estimate the absolute reliability of free-living habitual physical activity and sedentary behaviour for both devices. The strength of the reliability measure is that it estimates the behavioural variation from week-to-week and not day-to-day. This method provides a measure of reliability for habitual patterns of behaviour in a free-living condition that is a more useful measure for large-scale epidemiologic studies assessing behavioral patterns of physical activity and sedentary behaviour over the long-term and its impact on health outcomes.

5.9 Study limitations

It is important to take into consideration methodological shortcomings when comparing and evaluating two methods of measurement. This study was able to assess the convergent validity of the ActiGraph® GT3X+ and the activPAL3® monitoring devices. The largest limitation is the lack of a gold standard comparison, such as direct observation, in order to estimate the concurrent validity of both monitors. Without a gold standard comparison, it is impossible to say which device is more accurately measuring physical activity and sedentary behaviour. Despite this shortcoming, the convergent validity still provides useful information since both devices are designed to measure the same parameters and by estimating the agreement between monitors, we can answer the question of whether or not these two devices can be used interchangeably. Furthermore, previous research has demonstrated that the activPAL® device provides reliable and accurate estimates of sitting time compared to direct observation and the activPAL® is arguably becoming the gold standard for device-based sedentary behaviour measurement.

Another study limitation with respect to these devices is error inherent to the devices themselves. Invalid data as a result of monitor error, participant error, matching both devices by date and time and applying the wear-time condition of at least four days recording for a minimum of 10 hours, decreased the sample size from a potential 281 to 225 recordings to compare the two devices (Figure 6). Using accelerometers in large epidemiologic studies poses a challenge with participant adherence to study protocol, including wearing the device properly and for the correct number of days which reduces study power. This study had a large sample of

270 participant files, and reductions in valid data used in analysis did not have an effect on the ability to detect a true statistical difference between devices.

Another study limitation is the narrowness of the study sample and thus the broader generaliability of the study findings. The study participants were enrolled in a randomized contolled exercise intervention trial and study inclusion criteria was very specific and tightly controlled. The generalizability of findings is limited to a similar study population and comparisons of physical activity and sedentary behaviour estimates using these devices to other study samples would provide inaccurate results.

5.10 Generalizability of findings

This study used a very specific volunteer population of previously inactive post-menopausal women. The study sample had no major co-morbidities such as previous cancers, cardio-vascular disease or diabetes. With no major biases introduced into the methods affecting the comparison of outcome variables using the two devices, it is concluded that this study is internally valid and therefore it is appropriate to discuss these findings and methods to other populations. The criteria for selection into the BETA Trial were stringent to ensure participants had a physiologic profile that would respond to an exercise intervention and in whom it would be possible to detect an effect of exercise on various intermediate biomarkers hypothesized to be associated with breast cancer. In addition, these participants were selected as they were more likely to be willing to commit to this intervention and adhere to the year-long exercise intervention. Considering the factors for participant selection it is assumed that they were a representative sample of post-menopausal women. The results comparing estimates of physical

activity intensity and sedentary behaviour between both devices may be generalized to a similar population of postmenopausal women. Comparisons of overall estimated time in physical activity and sedentary behaviour using these devices in separate populations would provide inaccurate results.

For the purpose of automated data processing, the population under study will influence the algorithm used. The algorithm used to automatically process these data was a result of this study population and to some extent the trial participants were currently undergoing. The same algorithm used for this study may not be applicable to a similar study design aimed to estimate physical activity and sedentary behaviour in children. Children may have very different wear and non-wear periods and the non-wear window used in the algorithm of choosing may differ to reflect the length and frequency of non-wear in the population under study.

5.11 Future recommendations

Several recommendations for future research comparing these two devices can be considered. An initial recommendation is to assess the concurrent validity and compare estimates of physical activity and sedentary behaviour to a gold standard. The concurrent validity will provide researchers with a more thorough answer to the question of which device to use for the purpose of estimating physical activity and sedentary behaviour, if only one can be chosen. A few algorithms have been previously developed and easily adaptable for the ActiGraph® device for the purpose of automatic processing for a large number of files. No algorithms have been validated and tested for use with the activPAL® device. This study attempted to use sitting time as a surrogate measure of count data to detect non-wear. A threshold of prolonged sitting, such

as 60 or 90 minutes, may indicate the device has been removed. This concept, however, performed poorly with these data and was not subsequently used in analysis. Future research should develop algorithms to use with the activPAL® device. One method of using this approach that has recently been proposed, is to use the 15 second epoch file generated by the activPAL® software. This file contains count-like data that may indicate, similar to count data from the ActiGraph®, when the device was worn and not worn. Although 15 second epoch files were used in this analysis, these count-like data were omitted because of software problems with PALtechnologies that prohibited the use of these data.

New developments in processing accelerometer data are currently being developed. One such method known as artificial neural networks (ANN) has been developed by Dr. Patty Freedson and colleagues at the University of Massachusetts, Amherst (81). These artificial neural networks are non-linear regression models that are used to model a relation between a response, usually METs or physical activity type and covariates such as accelerometer counts or person specific information such as height weight and age (81). These sophisticated artificial neural networks may improve performance in estimating energy expenditure and physical activity type. One reason may be because the neural network method uses more information in the accelerometer signals compared to minute-by-minute data used in traditional cut-point methods. Furthermore, these artificial neural networks may be customized for individual accelerometer recordings, potentially providing a more accurate assessment of physical activity and sedentary behaviour. It has been noted that single methods of processing data for an entire sample, including neural networks and the traditional cut-point method, produce small mean differences

in estimates of behaviours under question at the group level but individual differences may be substantial (81).

Although our study's aim was to compare estimates of physical activity and sedentary behaviour from these two accelerometers, these data may be used and analyzed in different ways. The BETA Trial collected accelerometer data at four different time points including baseline, six, 12, and 24 months. These accelerometer data can be analysed between time points in the trial and change scores can be estimated. This estimate can provide objective information at the group and individual level to examine change in activity patterns and duration as the trial moves forward. The BETA Trial has collected extensive information on various biomarkers and these objective measures of physical activity can be used to examine associations between objective measures of physical activity and sedentary behaviour and changes that occur in the biomarkers under investigation. Subsequently, objective measures of sedentary behaviour can provide valuable information in relation to biomarker change.

Collection of accelerometer data on large samples poses many challenges, including potential error in monitor recording such as battery failure. The most challenging aspect is ensuring the accurate wearing of the device by participants, including wearing the device properly and for the correct number of days and hours per day to obtain the minimum amount of data to produce accurate measures of physical activity and sedentary behaviour. Accurate recording of wear-time via diary logs should be kept as simple as possible to ensure continuity of data between participants, such as recording time on a 24-hour or 12-hour clock and to reduce participant burden in filling out information on a daily basis. Protocols should be implemented to track and confirm devices are returned on time and participants are re-doing recordings that were

missed or invalid. Furthermore, protocols should be implemented for picking-up and dropping off devices and include using secure locations and packaging for devices.

5.12 Conclusion

This study found that, at the group level, the median differences between ActiGraph® VT, VM and the activPAL3® are small for each comparable behaviour category. Statistically significant differences occurred between methods at the group level for all physical activity intensities, with the exception of moderate activity between ActiGraph® VM and activPAL3®. No statistically significant differences occurred between the ActiGraph® VM and activPAL3® and ActiGraph® VT and activPAL3® for total time in sedentary behaviour. Despite the statistically significant differences between methods for aggregate median time in most activity intensities, at the group level, these differences may be negligible. At the individual level, agreement between methods is poor with large limits of agreement for comparable behaviours, indicating these two devices may not be used interchangeably. Future studies using a gold standard comparison can confirm which device is more accurately capturing true physical activity and sedentary behaviour status. For use in large scale epidemiologic studies, algorithms for automatic processing of activPAL® data should be developed and tested on several populations, including children and older adults.

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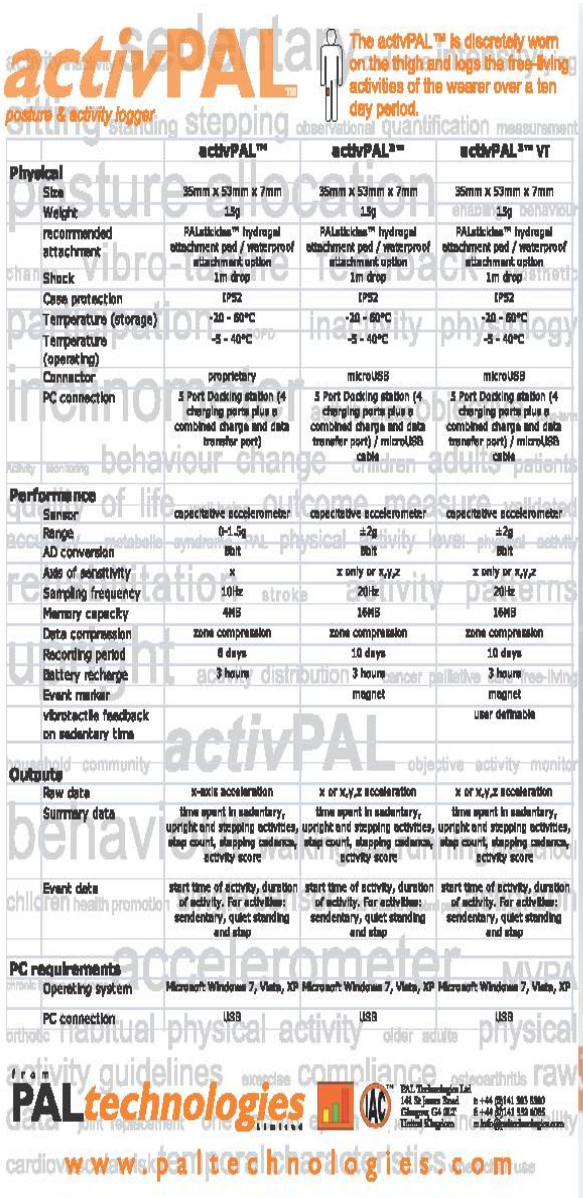
A.1. ActiGraph GT3X+ Specifications

Dimensions	4.6cm x 3.3cm x 1.5cm
Weight	19 grams
Sample Rate	30 – 100 Hertz in 10 Hz Increments
Memory / Storage Capacity	512 MB
Battery Life	30 Days (Fully Charged)
Communication	Full-Speed USB 2.0. Full device download in less than 45 sec.
Water Resistant	1 meter for 30 minutes
Lux Range	350-850 nm, 600 nm peak
Transducers	Tri-axis, solid state accelerometer Ambient Light Photodiode
Dynamic Range	+/- 6G
Capacity	40 Days (Raw data at 30 Hz)*
Resolution	12-bit A/D conversion; 2.93 mG (Raw Data)
Parameters	Activity, Steps, Inclinometer, Light
Calibration	Not Required

*40 days at 30Hz sample rate. Recording time is reduced with increased sample rates. Device can record approximately 16 days at 80Hz. See manual for details.

A.2. activPAL Specifications:



activPAL™
posture & activity logger

The activPAL™ is discretely worn on the thigh and logs the free-living activities of the wearer over a ten day period.

		activPAL™	activPAL²™	activPAL³™ VT
Physical				
	Size	35mm x 53mm x 7mm	35mm x 53mm x 7mm	35mm x 53mm x 7mm
	Weight	15g	15g	15g
	recommended attachment	PALstickies™ hydrogel attachment pad / waterproof attachment option	PALstickies™ hydrogel attachment pad / waterproof attachment option	PALstickies™ hydrogel attachment pad / waterproof attachment option
	Shock	1m drop	1m drop	1m drop
	Case protection	IP52	IP52	IP52
	Temperature (storage)	-20 - 60°C	-20 - 60°C	-20 - 60°C
	Temperature (operating)	-5 - 40°C	-5 - 40°C	-5 - 40°C
	Connector	proprietary	microUSB	microUSB
	PC connection	5 Port Docking station (4 charging ports plus a combined charge and data transfer port)	5 Port Docking station (4 charging ports plus a combined charge and data transfer port) / microUSB cable	5 Port Docking station (4 charging ports plus a combined charge and data transfer port) / microUSB cable
Performance				
	Sensor	capacitative accelerometer	capacitative accelerometer	capacitative accelerometer
	Range	0-1.5g	±2g	±2g
	AD conversion	8bit	8bit	8bit
	Axis of sensitivity	x	x only or x,y,z	x only or x,y,z
	Sampling frequency	10Hz	20Hz	20Hz
	Memory capacity	4MB	16MB	16MB
	Data compression	zone compression	zone compression	zone compression
	Recording period	6 days	10 days	10 days
	Battery recharge	3 hours	3 hours	3 hours
	Event marker		magnet	magnet
	vibrotactile feedback on sedentary time			user definable
Outputs				
	Raw data	x-axis acceleration	x or x,y,z acceleration	x or x,y,z acceleration
	Summary data	time spent in sedentary, upright and stepping activities, step count, stepping cadence, activity score	time spent in sedentary, upright and stepping activities, step count, stepping cadence, activity score	time spent in sedentary, upright and stepping activities, step count, stepping cadence, activity score
	Event data	start time of activity, duration of activity. For activities: sendentary, quiet standing and step	start time of activity, duration of activity. For activities: sendentary, quiet standing and step	start time of activity, duration of activity. For activities: sendentary, quiet standing and step
PC requirements				
	Operating system	Microsoft Windows 7, Vista, XP	Microsoft Windows 7, Vista, XP	Microsoft Windows 7, Vista, XP
	PC connection	USB	USB	USB

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Appendix A.3. Activity Monitor log

7008

Alberta Health Services

Study ID

Activity Monitor Daily Log

7008

Activity monitor instructions

What is the activity monitor?

The **ActiGraph GT3X Plus** activity monitor is about the size of a wristwatch. This activity monitor is a motion sensor that records how often and how quickly movements are made. When worn on your body (on a belt, at your waist), the monitor records your physical activity. The activity monitor is a small, non-invasive device and will not interfere with usual daily activities or function.

The **activPAL** is a small device that acts much the same as the ActiGraph. This activity monitor will provide information on body position and movement. When worn on your body (with a PALsticky™ on the front mid-line of the thigh) the monitor will record your daily activity. This is a non-invasive device that should not interfere with daily activities or function.

Note: Wear these two devices at the same time

As a participant in the study, what do you need to do?

- Wear the activity monitors every day for a period of ***seven days***.
    - To wear the ActiGraph GT3X Plus activity monitor, you will place a belt with the monitor attached to it around your waist. The monitor should always be worn on the right side of your body. The belt and monitor should be worn as close to your body as possible - underneath your clothing is best. Wear the monitor so that the back of the red box (screws showing) is against your right side. Be sure that the monitor is snug against your waist when worn.
    - To wear the ActiPAL activity monitor, you will place a PALsticky™ on the back portion of the activPAL and subsequently place the device on the front mid line portion of the right thigh. Skin should be free of creams and ointments to ensure the PALsticky™ and activPAL device are securely attached to the limb. Replace the PALsticky™ when you feel the activity monitor is not securely attached to the thigh.
- Fill in the daily log ***each day*** to indicate when you put on and removed the monitors.

What you need to do each day:

1. ***Put on the activity monitors*** right after you get out of bed in the morning and record this time in the activity log.
2. ***Wear the activity monitors*** throughout the day, even when you may take a nap.
    - The monitors are **NOT waterproof** - so PLEASE do not wear them in the bath or shower or if you go swimming.
    - If there are any times of the day that you do **NOT** wear the monitors between getting up in the morning and going to bed at night, ***please fill in the daily log*** as described on the next page.
3. ***Take off the activity monitors*** just before you get in bed at night and record this time in the activity log.

7008

Daily log instructions

For any period of time that you did NOT wear the monitor between getting up in the morning and going to bed at night, list:

- what activity you were doing
- the time you started the activity
- the time you stopped the activity

You may combine routine activities but other activities should be reported separately.

Examples of activities considered to be "routine activities" that may be combined are:

- Taking a shower
- Shaving
- Drying your hair
- Getting dressed
- Applying make-up
- Preparing & eating breakfast
- Brushing your teeth
- Getting ready to go to bed

* Only record activities lasting **10 MINUTES** or longer.

Example:

You went for a swim so you had to remove the monitor. You were swimming from 8:30 until 9:00 am then you changed into your clothes and put the monitor back on. In the daily log, you would list the following:

What activity were you doing? *Went Swimming*

At what time did you start this activity? *8 : 3 0* (24 Hour)

At what time did you stop this activity? *9 : 0 0* (24 Hour)

You do **NOT** need to list the time you spent changing into exercise clothes if it took less than 10 minutes.

You do **NOT** need to list the time you were showering and changing clothes if it took less than 10 minutes.

7008

Frequently asked questions

1. **After I swim, I typically spend 20 minutes in the locker room getting ready to leave. What if I put on the monitor after I am done getting ready? What should I write in the log?**

   Answer: Because getting ready took more than 10 minutes, you need to tell us what activities you did in the locker room to get ready and leave. First, as in the example above, you would list the 30 minutes you went swimming. If from 9:00 to 9:20 am you took a shower, got dressed, and dried your hair, you would fill out the daily log as follows:

What activity were you doing?	*Took a shower, got dressed, dried my hair*
At what time did you start this activity?	*9* : *0 0* (24 Hour)
At what time did you stop this activity?	*9* : *2 0* (24 Hour)

2. **Why did you combine "took a shower, got dressed and dried my hair" into one statement? I would have separated those activities.**

   Answer: We consider taking a shower, getting dressed and drying hair to be routine activities. You can combine routine activities.

3. **What if I forget to wear the monitor for part of the day?**

   Answer: We hope you will wear the monitor throughout the day. However, if you do forget, you will need to list each activity you did during that period of time. For each activity, you will need to list the time the activity began and ended.

****Remember** - the only times that you need to **take off** the activity monitor during the day are when you are doing a water-based activity.

7008

DAY 1

Day ☐☐ / Month ☐☐ / Year 2 0 ☐☐

M T W Th F Sa Su
O O O O O O O
(Shade bubble for day of week)

What time did you get out of bed this morning? ____:____ (24 Hour)

What time did you put on the monitor this morning? ____:____ (24 Hour)

What time did you take off the monitor this evening? ____:____ (24 Hour)

What time did you get into bed this evening? ____:____ (24 Hour)

Did you wear the monitor all day? (Shade bubble) Yes O No O

IF NO, answer the following questions.

For any period of time that you did NOT wear the monitor between getting up in the morning and going to bed at night, list: what you were doing, the time you began, and the time you stopped. You may combine routine activities but other activities should be reported separately. Only record activities lasting **10 MINUTES** or longer.

List activities you did when you were NOT wearing the monitor

What activity were you doing? _____

At what time did you start this activity? ____:____ (24 Hour)

At what time did you stop this activity? ____:____ (24 Hour)

What activity were you doing? _____

At what time did you start this activity? ____:____ (24 Hour)

At what time did you stop this activity? ____:____ (24 Hour)

What activity were you doing? _____

At what time did you start this activity? ____:____ (24 Hour)

At what time did you stop this activity? ____:____ (24 Hour)

Appendix A.4. Baseline Health Questionnaire

56524

Day / Month / 2 0 1 Year

beta trial

Baseline Health Questionnaire

This questionnaire asks questions about you and your health.

GENERAL INSTRUCTIONS

Answer every question by marking the answer as indicated.

If you are unsure about how to answer a question, please give the best answer you can.

If a question does not apply to you, please ensure that you answer "No" to the question and proceed to the next.

Alberta Health Services

A. DEMOGRAPHIC INFORMATION

A1. When were you born? ☐☐ / ☐☐ / ☐☐☐☐
Day Month Year

A2. What is your current marital status?

- O Married
- O Common-law
- O Separated
- O Divorced
- O Widowed
- O Never Married
- O Other (specify) _____

A3. What is the highest level of school that you have completed?

- O Did not complete grade school
- O Grade school
- O High school
- O College or trade school
- O University undergraduate degree/Nursing school
- O University graduate degree

A4. To which ethnic or cultural groups did you, or most of your ancestors belong, on first coming to North America? (Check all that apply)

- O British
- O Western European
- O Eastern European
- O French
- O Northern European
- O Southern European
- O Aboriginal
- O East and Southeast Asian
- O Southern Asian
- O Western Asian
- O Pacific Islands
- O Arab
- O Latin, Central and South American
- O Caribbean
- O African
- O Other (specify) _____

B. MENSTRUAL HISTORY

B1. How old were you when your menstrual periods started?

☐☐ (years)

B2. What statement best describes your menstrual status one month before today?

- O Still having periods and not going through menopause or change of life.
- O Still having periods and possibly going through change of life.
- O Going through menopause or change of life.
- O Periods stopped by themselves or natural menopause.
- O Periods stopped by surgical removal of the uterus or both ovaries.
- O Periods stopped by radiation or chemotherapy.
- O On hormone replacement therapy and still having periods.
- O Other (specify)_____
- O Don't know

B3. How old were you when had your last menstrual period? (After your menstrual periods stopped, you may have started taking hormones that caused you to start having periods again. We are interested in when your menstrual periods stopped before you started taking these hormones.)

☐☐ (years)

Note: Remembering major life events will help you pinpoint your exact age at which your menstrual periods stopped.

B4. Have you had a hysterectomy? A hysterectomy is an operation to remove your uterus or womb.

- O Yes
- O No

If yes, how old were you when you had the operation? ☐☐ (years)

B5. Have you had both ovaries removed?

- O Yes
- O No
- O Don't know

If yes, how old were you when you had the operation?
(However if both have been removed in two separate operations, provide the age at which you had the second operation) ☐☐ (years)

C. REPRODUCTIVE HISTORY

C1. Have you ever been pregnant?

O Yes If no, go to section D

O No

C2. How many pregnancies have you had?

☐☐ **Total number of pregnancies including miscarriages, abortions, still births and live births**

C3. How many live births have you had?

☐☐ Total number of pregnancies that resulted in live births

***Note:** Having twins or triplets will still be considered as <u>one</u> pregnancy.*

C4. How old were you when your first child was born?

☐☐ **years**

D. MEDICAL HISTORY

D1. Have you ever been diagnosed with any of the following conditions?

High cholesterol or triglycerides	**O Yes**	**O No**
Heart attack (myocardial infarction)	**O Yes**	**O No**
Cardiac chest pains (angina pectoris)	**O Yes**	**O No**
Stroke	**O Yes**	**O No**
Arthritis (rheumatoid arthritis or osteoarthritis)	**O Yes**	**O No**
Osteoporosis/Osteopenia	**O Yes**	**O No**
Blood clots in the veins of your legs or pelvis	**O Yes**	**O No**
Blood clot in your lungs	**O Yes**	**O No**
Thyroid problems	**O Yes**	**O No**
Hip Replacement	**O Yes**	**O No**
PCOS (Polycystic Ovary syndrome)	**O Yes**	**O No**
Any other medical conditions	**O Yes**	**O No**

If yes, what conditions?

D2. **Have any of your mother, daughters or sisters had breast cancer? Do not include any stepsisters, half sisters or adopted sisters.**

O Yes O No

D3. **Have you ever been told by a doctor that you have benign breast disease, i.e., a breast condition or disorder that is not cancerous?** *The doctor may have referred to it as fibrocystic breast disease or breast cysts, lumps etc.*

O Yes O No

If yes, was a breast biopsy taken? *A breast biopsy is a small operation that involves removing a piece of your breast tissue in order to diagnose a breast problem.*

O Yes O No

E. ANTHROPOMETRIC HISTORY

E1. **What is the tallest you have ever been without shoes on?**

☐ feet and ☐☐.☐ inches or ☐☐☐.☐ cm

E2. **What was your body weight at the following ages? (use your usual body weight, when you were not pregnant.)**

20 years	☐☐☐ **lbs**
30 years	☐☐☐ **lbs**
40 years	☐☐☐ **lbs**
50 years	☐☐☐ **lbs**
60 years	☐☐☐ **lbs**
70 years	☐☐☐ **lbs**

Note: *Try to remember major life events that occurred at these ages and the weight you were (e.g. graduations, marriages, etc.)*

F. MENOPAUSAL HORMONE USE HISTORY

F1. Have you ever used any hormone medications, in the form of a pill, shot, implant, skin patch, body gel, vaginal cream, or suppository for the purpose of hormone replacement therapy?

O Yes (Please complete table) O No (Go to Section G)

Table of Menopausal Hormone Use

Please tell us the type of hormone you used (brand name or description), the age you started and stopped using the hormone, how long you used the hormone, the dose, and the mode in which you used it.

Type of hormone brand name or description	Age started	Age stopped	Duration of use	Dose	Units	Mode
	□□ years	□□ years	□□ ○ month(s) ○ year(s)	□□□□□ O don't know	O ug O mg O grams O other _____	O pill O patch O cream/gel O injection O other
	□□ years	□□ years	□□ ○ month(s) ○ year(s)	□□□□□ O don't know	O ug O mg O grams O other _____	O pill O patch O cream/gel O injection O other
	□□ years	□□ years	□□ ○ month(s) ○ year(s)	□□□□□ O don't know	O ug O mg O grams O other _____	O pill O patch O cream/gel O injection O other
	□□ years	□□ years	□□ ○ month(s) ○ year(s)	□□□□□ O don't know	O ug O mg O grams O other _____	O pill O patch O cream/gel O injection O other

G. MEDICATION USE

The next section is about <u>prescription and over-the-counter</u> *medications that you have taken in the past year.*

During the past 12 months, did you take any medications (prescription or over the counter) on a regular basis? ***"Regular"*** *is defined as at least 3 times a week for at least 1 month.* ***<u>Do not include</u> Hormone Replacement Therapy (HRT) medications or vitamins and minerals.***

O Yes (Please complete table) O No (Go to Section H)

Name of medication	What dose do/did you take regularly	Units of dose	How often do/did you take it?	How long have/had you been taking it?
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know

Name of medication	What dose do/did you take regularly	Units of dose	How often do/did you take it?	How long have/had you been taking it?
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know

H. Vitamin and Supplement Use

The next section is about <u>vitamins and supplements</u> *that you have taken in the past year.*

During the past 12 months, did you take any vitamins or supplements, on a regular basis? ***"Regular"*** *is defined as at least 3 times a week for at least 1 month.* ***Do not include medications.*** *On the opposite page, you also have the option of listing any vitamins or minerals you may take that are not in a pill or dose form*.*

O Yes (Please complete table) O No (Go to section H)

Name of vitamin or supplement	What dose do/did you take regularly	Units of dose	How often do/did you take it?	How long have/had you been taking it?
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know

Name of vitamin or supplement	What dose do/did you take regularly	Units of dose	How often do/did you take it?	How long have/had you been taking it?
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
	☐☐☐☐☐☐	○ ug ○ L ○ mg ○ units ○ grams ○ IU ○ mL ○ don't know	☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know

*Please list any other supplemental vitamins and minerals you may take that are not in pill or dose form (e.g. soy milk, Ensure). Please list the name of the supplement, the quantity you take and how often, as well as how long you have been taking the suppplement.

Name of vitamin or supplement	What quantity did/do you take regularly?	How often did/do you take it?	How long have/had you been taking it?
		☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
		☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know
		☐☐ times ○ per day ○ per week ○ per month ○ don't know	☐☐ ○ days ○ week(s) ○ month(s) ○ year(s) ○ don't know

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THANK YOU FOR COMPLETING THIS QUESTIONNAIRE !

Appendix A.5. Ethics Approval

Conjoint Health Research Ethics Board (CHREB)
Research Services Office
Main Floor, Energy Resources Research Building
Research Park
Telephone: (403) 220-7990
Fax: (403) 289-0693
Email: resethic@ucalgary.ca

January 23, 2014

Dr. C. Friedenreich
Division of Epidemiology, Prevention and Screening
Alberta Cancer Board
Tom Baker Cancer Centre
Holy Cross Centre,
Box ACB,
2210-2nd Street SW,
Calgary, AB T2S 3C3

Dear Dr. Friedenreich:

Re: Breast Cancer and Exercise Trial in Alberta the BETA Trial

Ethics ID: 23022

Please accept this letter as confirmation that Mr. Ted Pfister's thesis work entitled **"The convergent validity and test-retest reliability of two accelerometers for measuring physical activity and sedentary behaviour in a healthy population of older women"** was part of the above study which has received ethics approval.

Sincerely,

Stacey A. Page, PhD
Chair, Conjoint Health Research Ethics Board
Assistant Professor
Department of Community Health Sciences
SAP/eb

c.c. Mr. Ted Pfister