QUANTIFYING PHYSICAL ACTIVITY IN COMMUNITY DWELLING OLDER ADULTS USING ACCELEROMETRY

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Background: A physically inactive lifestyle is associated with an increased risk for a variety of chronic diseases and health conditions. One population at greatest risk of physical inactivity is older adults.

Studies: The specific aims for my dissertation research focused on further development of the Actigraph accelerometer to measure physical activity in community dwelling older adults. I proposed to first further define what an "activity count" from the Actigraph accelerometer represents. By comparing Actigraph counts to raw accelerometry, oxygen consumption and pedometer step count data at usual and slow walking speeds we found that counts per second were correlated with raw accelerometry and energy cost. Actigraph counts, raw acceleration, pedometer step counts and oxygen consumption were higher for usual versus slow walking conditions as expected. We were able to formulate a regression equation to estimate energy cost from Actigraph counts in community dwelling older adults. For the next project, I investigated the reliability and validity of the various ways to present data from the Actigraph accelerometer. All Actigraph measurement units of interest were highly correlated with each other as well as with performance based measures of mobility, function, age and self reported physical activity. Actigraph counts per minute and standard deviations of counts were able to distinguish between low and high mobility and functioning groups. Using ROC curves, we established a cut off value of 150 counts per minute to detect mobility and function problems. Finally, I determined meaningful change values of physical activity measured by the Actigraph over a 12 week exercise intervention in community dwelling older adults with walking difficulty. We found a value of 30 counts per minute to indicate substantial change beyond spurious error. Actigraph counts per minute did not change over the course of exercise intervention. However, people who were more active at baseline exhibited improvements in mobility and functional measures compared to those who were less active at baseline.

Conclusion: From the projects described above, Actigraph counts have been validated in older adults against raw accelerometry, oxygen consumption, mobility, function, and self-reported physical activity measures. Inter-rater reliability was excellent for the multiple outputs of the Actigraph accelerometer. Actigraph counts per minute data output is our recommendation since it is the default output, has the least amount of processing, produces high inter-rater reliability and validity against mobility and function.

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PREFACE

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1 INTRODUCTION

1.1 IMPACT OF PHYSICAL INACTIVITY IN OLDER ADULTS

Physical activity is a broad term which was defined by Caspersen in 1985 in Public Health Reports as "any bodily movement produced by skeletal muscles that results in an increase in energy expenditure above resting levels." *Physical inactivity* is a term used to describe behavior not people [1] and can be defined as a state in which bodily movement is minimal [2]and/ or does not meet recent public health guidelines. [3,4] A physically inactive lifestyle is associated with an increased risk for a variety of chronic diseases and health conditions such as cardiovascular disease,[5-8] hypertension, [9-11] diabetes mellitus,[12-15] certain cancers,[16-18] depression,[19-21] obesity,[22,23] cerebrovascular disease, and premature death.[24] One population at greatest risk of physical inactivity is older adults. To achieve health benefits, the U.S. Centers for Disease Control and Prevention recommends 30 minutes of moderate intensity activity (approximately 150 kcal/day) [24] on most days of the week; however more than half of older adults report no moderate intensity activity. [24-27] The US Department of Health and Human Services has set a national health objective for 2010 to reduce the prevalence of no leisure time activity from more than 25% to 20% of US adults.[28] Before health care professionals can effectively assist in increasing physical activity they need to accurately define and measure activity in older adults. Current methods of evaluating physical activity in older adults such as self report measures and pedometers are not ideal since the former relies on patient recall and is limited by response bias and the latter can undercount steps taken in those who walk slowly, are obese, or have abnormal walking patterns.

Accelerometers are electronic motion monitors that detect the frequency, intensity and duration of ambulatory activity. Physical activity measured by accelerometers has been studied in the general populous to establish the reliability and validity with measures of energy expenditure, other accelerometers, self report measures and direct observation. However, accelerometers are less studied in older adults even though they provide a promising measure of activity in this population.[29] Specifically, the relation of physical activity information from accelerometers to functional outcomes in older adults is a novel and understudied area of research. Investigators use multiple models and brands of accelerometers all of which are not equal and report the accelerometry data differently making comparisons challenging.

The specific aims for my dissertation research focus on further development and understanding of the Actigraph accelerometer (Actigraph, LLC, Fort Walton Beach, FL) to measure physical activity in community dwelling older adults. I propose to first further define and explain what an "activity count" from the Actigraph accelerometer represents. I then plan to investigate the reliability and validity of the various ways to present data from the Actigraph accelerometer. Finally, I plan to establish the meaningful change values and responsiveness of physical activity measured by the Actigraph over a 12 week long exercise intervention in our community dwelling older adults with walking difficulty.

1.2 SPECIFIC AIMS AND HYPOTHESES

1.2.1 Specific Aim I

To Compare Processed and Raw Physical Activity Accelerometry Data and Oxygen Consumption during Ambulation in Community Dwelling Older Adults.

1.2.1.1 Hypotheses I

Our hypotheses are as follows: 1) For both usual and slow walking conditions a higher number of activity counts from the Actigraph accelerometer would be correlated with a larger magnitude of force (in G's) from the BIOPAC accelerometer, higher energy expenditure, and higher number of steps on the pedometer; 2) For usual versus slow walking conditions participants will have higher activity counts, a larger magnitude of force, and a higher energy expenditure; and 3) The regression equation estimating energy expenditure from activity counts formulated from this study will more precisely estimate actual energy cost in older adults than Freedson's equation previously tested in younger adults.

1.2.2 Specific Aim 2

To Establish Inter-Rater Reliability and Known Groups Validity of Actigraph Accelerometry Physical Activity Data with Known Function Groups in Community Dwelling Older Adults

1.2.2.1 Hypothesis 2

We expect inter-rater reliability (ICCs) will be high for Actigraph outputs of interest [activity counts per minute, variability of activity (standard deviation of activity counts), 5 minute bouts of activity and 10 minute bouts of activity]. We also hypothesize that Actigraph outputs of interest would be positively associated with the mobility, performance based function, self reported physical activity and negatively associated with age, fear of falling (SAFFE fear sub-scale), and self reported activity restriction (SAFFE- restriction subscale). Finally we anticipate that those participants who had better mobility (SPPB $\geq$ 10) and performance based function (75^{th} percentile of PPT scores) would have higher activity counts per minute, greater standard deviation of activity counts, more 5 and 10 minute bouts of activity and higher minutes of moderate intensity activity than those with lower mobility and function.

1.2.3 Specific Aim 3

To Determine the Responsiveness of Actigraph Accelerometry Physical Activity Data with Exercise Intervention in Community Dwelling Older Adults.

1.2.3.1 Hypothesis 3

We will establish anchor and distribution based interpretation of meaningful change scores for the Actigraph accelerometer counts per minute measurement. We expect the participants who improved in mobility (Gait speed) and physical performance based function (PPT scores) after the 12 week exercise program will exhibit the greatest increase in activity counts per minute followed by those who have not changed then lastly those who had worsened in their mobility and function.

1.3 BACKGROUND

1.3.1 What are the instruments available to measure physical activity?

1.3.1.1 Self Report Techniques

Self-reporting techniques consist of questionnaires and diaries.[30,31] Physical activity questionnaires are able to address the type, frequency, intensity, duration and domains of physical activity (i.e. self care, occupation, leisure, sport) over a specific timeframe (day, week, month, year, or even lifetime). Numerous physical activity questionnaires currently exist and a thorough summary was presented in 1997 through a special supplement to the Medicine and Science in Sports and Exercise journal.[32] The supplement provides instructions for administration and scoring, psychometric properties, and relevant articles for a collection of more than 30 physical activity questionnaires. Also, numerous detailed reviews have reported the reliability and validity of physical activity questionnaires.[32-41] Diaries are self administered, with the participant making entries of all their physical activities over short time frames, such as a 24 hour period.[42] Diaries are an inexpensive way to ascertain comprehensive information on type (household, leisure, occupational), pattern, and duration of physical activities. Diaries have been validated in comparison to activity monitors [43], other self report measures of physical activity [44], and measures of energy expenditure. [44] Using the information obtained from questionnaires and diaries the intensity (the metabolic cost or energy cost of the physical activity) [42] can be estimated. Comprehensive lists of energy requirements for physical activities are available to estimate the intensity of the specific activities of interest.[45-49]

Participant recall, seasonal effects, and issues with estimating activity have been shown to systematically influence self report measures of physical activity. Error associated with participant recall is estimated to be between 35 and 50% with varying rates associated with age groups or disease conditions[50]. Reporting of physical activity can also be affected by social desirability bias, where an individual over-reports their physical activity level since they believe that society and/or the investigator looks down upon physical inactivity.[50-52] There is some evidence in the literature to suggest that interviewer administered questionnaires are superior to self-administered questionnaires.[34]

Seasonal effects are variations of temperature and precipitation associated with seasons providing a potential environmental deterrent to physical activity.[53-55] Self report measures with longer timeframes can be less subject to seasonal effects than questionnaires with shorter time frames. Several studies in geographic areas subject to seasonal effects found greater amounts of leisure time energy expenditure in the more temperate summer and spring months than in fall and winter months. [54-56]

When estimating energy expenditure from the information obtained through self report measures, it appears that individuals are reasonably accurate in recalling high intensity activity such as running, or vigorous sport activities [57,58] but are less accurate in recalling light to moderate intensity activities such as walking, and some household chores.[59-62] The investigator must also be aware that physical activity can be performed at a range of skill levels and differing speeds. Therefore, the actual energy expended across participants who report the same amounts of time in a particular activity may vary considerably.[59,63]

1.3.1.2 Pedometers

Pedometers are matchbook-sized, battery-operated movement monitors that are attached to the waistband in the midline of the thigh on either side of the body. Pedometers were designed to measure the number of steps that a person takes during ambulatory activity such as walking or running. Pedometers count the number of steps taken during ambulatory activity by using a horizontal spring suspended lever arm that moves up and down in response to vertical accelerations of the hip. This motion opens and closes an electrical circuit, which accumulates the number of steps taken and provides a digital display. The raw data (number of steps accumulated) are the most accurate descriptor of ambulatory activity obtained from a pedometer.[64,65]

Older mechanical-style pedometers had problems with reliability and validity, but the new electronic pedometers are more accurate.[30,66-68] Pedometers range in cost from approximately $10 to $200,[69] which makes them an attractive low-cost choice. Pedometers have gained attention over the past decade because of their ability to provide accurate measures of ambulatory behaviors and to capture intermittent or continuous activity participation throughout the assessment period of interest. The pedometer can be remarkably accurate in counting steps in people without impairments who walk at least 0.9 m/s.[70] However, the use of pedometers in measuring physical activity in older adults has limitations. First, pedometers may underestimate steps taken at slower gait speeds (ie, <0.9 m/s)[71-73] or with irregular and unsteady gait patterns.[71,72,74-76] Secondly, because pedometers were specifically designed to measure ambulatory behavior, they also may not accurately capture seated activity, upper-extremity activity, or indoor and outdoor household chores such as pushing, lifting, or carrying objects.[43,77,78] Thirdly, pedometers do not have internal clocks, so they are unable to provide information on the pattern or duration of specific activities (ie, how many steps a person accumulated at 2:00 PM while walking the dog). Finally, pedometers do not take into account the intensity of vertical displacement; therefore, the steps on a pedometer cannot distinguish one intensity level from another. For instance, if one person sprinted 100 steps and a second person walked 100 steps, the pedometer would simply record approximately 100 steps for each person.

1.3.1.3 Accelerometers

Accelerometers are electronic sensors able to measure and store real time estimates of the frequency, intensity, and duration of free living physical activity and movement.[30,79] Accelerometry data are recorded by the activity monitor and then processed on a computer. Most accelerometers use piezoelectric acceleration sensors consisting of a piezoelectric element and a seismic mass housed in an enclosure (See Figure 1). When acceleration occurs the seismic mass causes the piezoelectric element to either bend or compress. This in turn leads to build up of charge on one side of the sensor producing a voltage signal which is proportional to the applied acceleration. Acceleration is the change in speed with respect to time. Typically acceleration is measured in gravitational units (g's) where 1 g is equal to 9.8 m.s-2. When an object's acceleration is zero then that object may still be moving but at a constant speed. Since acceleration is proportional to the net external force involved it is more reflective of energy cost compared to speed. [80] The sampling frequency of accelerometers should ensure the full range of human motions including twice the frequency of the highest frequency movements. [81] The general frequency in normal non-impact physical activity is below 8 Hz however the upper limit may reach as high as 25Hz. [82] Accelerometers integrate a filtered digitized acceleration signal over user specified time interval called an epoch.[83] At the end of each epoch the summed activity count data is written to memory. Epoch length is not an issue if you are looking at overall volume of activity but to apply cut points to determine amount of time in different activity intensity levels the epoch length is of interest. One minute epoch lengths are often used for adult moderate to vigorous activity count cut points.

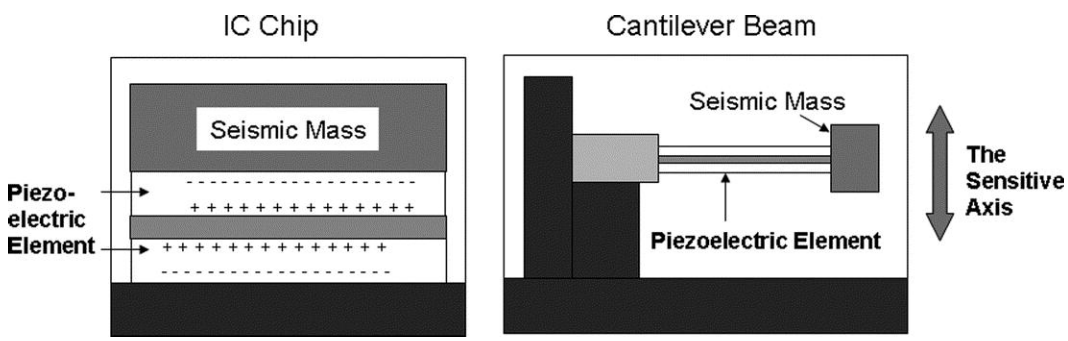

Figure 1 Schematic of two common pizoelectric accelerometer configurations

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Accelerometers can vary in size, weight, sensitivity, cost (approximately $600-$1,200), sturdiness, memory, and software capabilities.[83] Accelerometers are relatively small, and they can be worn on the waist, low back, wrist, or ankle and are attached by belts, pouches, belt clips, or ankle and wrist Velcro bands. Positioning on the waist, hip or low back are well suited for picking up accelerations that occur during normal ambulatory movement[59,83-85] and have been shown to yield the best prediction of energy expenditure.[85,86] The use of multiple accelerometers (i.e. wrist worn in addition to waist worn) in comparison to one accelerometer placement [77,86] has been investigated yet yields minor improvements in estimating energy expenditure not warranting the additional subject burden of wearing multiple units.[83]

Accelerometers are classified as uniaxial, biaxial, or triaxial depending on the number of planes in which movement is monitored. Uniaxial monitors record vertical acceleration in 1 plane, and biaxial monitors record acceleration in 2 planes. Triaxial monitors' record acceleration in 3 planes by 3 different accelerometers positioned internally at 90 degrees from one another. Output from each accelerometer is reported along with a composite value of all 3 accelerometers, possibly providing a more stable indicator of overall body movements. On average, the validity coefficients reported for multiple axis units have been marginally higher than those reported for uniaxial. However, triaxial accelerometers are more expensive than uniaxial accelerometers and the output from most uniaxial accelerometers are strongly correlated with output from multiple axis units suggesting that these accelerometers provide comparable information.[83]

Studies have suggested that 4 to 12 measurement days are needed for reliable accelerometery estimates of habitual daily physical activities.[42,54,87,88] Specifically for adults, 3 to 5 days of monitoring is required to reliably estimate the outcome variables typically in accelerometery studies. [42,87,88] The number of monitoring days depends on the setting, the population under study [i.e. children may require more days of physical activity monitoring (4-9 days)], [83] the study resources (low funded versus well funded), and the research question (need for population level or individual level estimates of habitual physical activity behaviors).[50]

Accelerometers can measure most types of physical activity that involve lower-extremity or trunk acceleration such as walking, running, and stair climbing. Inter-instrument and intra-instrument (test-retest) reliability of accelerometers (i.e. Tritrac R3D, Actigraph, ActiTrac, BioTrainer, Actical) has been performed by comparing outputs from accelerometers worn on opposite hips during ambulatory tasks [89-92] and by using high precision shakers or turntable devices over multiple trials [90,93-95]. This reliability testing reveals intraclass reliability coefficients ranging from 0.40 to 0.99. Activity data from accelerometers has been validated in both laboratory and free living conditions against other makes and models of accelerometers,[96,97] self report measures,[96] doubly labeled water, indirect calorimetry,[79]and oxygen consumption (VO2)[59] with correlation coefficients ranging from 0.45 to 0.91. Overall, validity correlates (ICC, Pearson, Spearman correlation) are higher for ambulatory activity (walking and running) than with activities of daily living. Because accelerometers are typically worn on the waist, measuring activities that involve upper-extremity movement or seated activities can be difficult. Therefore, accelerometer data may underestimate the energy expenditure of certain indoor and outdoor household chores (eg, vacuuming, mowing the lawn, gardening) and some recreational tasks.[59,59,79,79,98-100]

1.3.1.3.1.1 Actigraph accelerometer

The ActiGraph GTIM model (Actigraph, LLC, Fort Walton Beach, FL.) formerly known as the Computer Science and Applications (CSA) and Manufacturing Technology Inc.(MTI) is a uniaxial accelerometer 2 by 1.5 by 0.6 inches in size, detects accelerations in the range of 0.05-2.0 g. and has a frequency response of 0.25- 2.0 Hz. A twelve bit analog to digital converter samples at 30 hz. The Actigraph has a lithium rechargeable battery which, fully charged, holds 4.18 volts and is capable of providing a charge for 14 days. The GT1M model contains 1 megabyte of memory for data storage and will support 182 days of activity and step data using 1 min epochs (364 days of activity data alone) as long as the battery is kept charged. To initialize and download data, a reader interface unit is required which consists of a serial port connected to the computer. The default output of the Actigraph is activity counts but it also has pedometer and energy expenditure options available. According to the manufacturer, one count is equal to 4 mili G's and should be linearly related to the intensity of the partcipants' physical activity during that interval of time. Due to the significant correlations found in previous literature between energy expenditure and activity data from accelerometers, many investigators and device manufacturers have applied linear regression equations to monitors output (activity counts) to predict energy expenditure.[80] Freedson in a sample of young college aged subjects exercising on a treadmill at various set intensities (speed beginning at 3mph) while wearing an Actigraph accelerometer applied linear correlation approaches.[101] Using one minute cycles, the manufacturer and the work of Dr. Freedson established the following activity levels based on Actigraph output:

Light activity: Less than or equal to 1952 counts (less than 2.99 METS)

Moderate activity: 1953 to 5724 counts (3.0 to 5.99 METS)

Strenuous activity: 5725 to 9498 counts (6.0 to 8.99 METS)

Very Strenuous activity: Greater than 9498 counts (greater than 9 METS)

The Actigraph GT1M models cost $325.00 per accelerometer and the initial software start up package including software, accelerometer, USB cable, and an elastic belt is $689. Investigators can also purchase belt clips ($3.00 ea) for each accelerometer as well as a few belt pouches ($6.00) and elastic belts of various sizes ($10.00) so participants have some wear options.

1.3.2 What are measures of energy expenditure

Measures of energy expenditure are often utilized to validate physical activity assessments. Energy expenditure and physical activity are interrelated but not synonymous. Energy expenditure is the outcome of physical activity and is a reflection of gender, age, body mass and the efficiency of movement.[102] The theoretical basis underlying the use of an accelerometer to assess physical activity is that acceleration is directly proportional to the muscular forces and therefore is related to energy expenditure. [103,104] Measures of energy expenditure should not be considered direct measures of physical activity. [64]Energy expenditure can be estimated by heart rate monitoring, {Karvonen, 1984 91 /id}[105-107] doubly labeled water technique [108-110] direct calorimetry, and oxygen consumption. Most of these measures of energy expenditure are inconvenient, expensive to use and are performed in laboratory versus free living environments. Activity intensity is usually expressed in METs which is kilocalories per kilogram body mass per time. One MET represents the energy expended or metabolic rate of an individual at rest.[111] Therefore 10 METs of activity participation would require 10 times the metabolic rate at rest. Based on the CDC-ACSM position statement, physical activity can be further classified into activity levels by MET categories (light <3 METs, moderate 3-6 METs, and vigorous >6 METs).[112]

The main purpose of this project was to investigate accelerometry activity counts as our output of interest versus accelerometry estimated energy expenditure (METS and kilocalories) from the Actigraph for several reasons. Waist worn accelerometers such as the Actigraph often underestimate the energy expenditure of free living activities. [99] This is due to the inability of the Actigraph to capture energy expenditure from arm activity, standing postures, vertical work (i.e. uphill walking), pushing or pulling objects, carrying extra weight (i.e bookbags, computers), non-weightbearing exercises (i.e. cycling), exercise in the water, and activities that involve changes in horizontal accelerations. [80] Instead we focus on data outputs of activity counts because it is the default output with the least amount of error according to the manufacturer. We do address energy expenditure in Specific Aim 1 by investigating the relation of activity counts from the Actigraph accelerometer with actual energy expenditure using oxygen consumption in order to further explain and explore activity counts.

1.3.3 Why is quantifying physical activity using accelerometers valuable?

The assessment of physical activity using activity monitors is essential to: (1) determine whether physical inactivity is a problem in our patients or research participants, (2) detect change over time in patients or research participants (3) set goals for physical therapy or other interventions to increase physical activity, (4) provide incentive and track adherence to recommendations made for increasing physical activity, and (5) utilize physical activity as an outcome measure for physical therapy or other interventions. As stated in the *Guide to Physical Therapist Practice*,[113] physical therapists are involved in prevention of disease and promotion of health and wellness. Physical therapists should be involved in preventing physical inactivity in susceptible populations such as older adults (ie, primary prevention), decreasing the severity of disease through early diagnosis of physical inactivity and prompt intervention (ie, secondary prevention), and limiting the degree of disability and inactivity in people with chronic and irreversible diseases (ie, tertiary prevention).

2 COMPARISON OF ACCELEROMETRY BASED PHYSICAL ACTIVITY AND OXYGEN CONSUMPTION DATA IN OLDER ADULTS

2.1 INTRODUCTION

The negative health impact of physical inactivity is mounting in the United States. A physically inactive lifestyle increases the risk of many chronic health conditions all of which can result in difficulties with independent functioning and premature death.[5,6,10,12,15,17,18,20-24] One population at greatest risk of physical inactivity is older adults. [24] Before health care professionals can effectively assist in increasing physical activity they need to accurately define and measure activity in older adults. Current methods of evaluating physical activity in older adults such as questionnaires and pedometers are not ideal since the former relies on patient recall and the latter can undercount steps taken in those who walk slowly, are obese, or have abnormal walking patterns. [43,71-78]To date, most research into daily physical activity patterns of older adults has primarily relied on self-report measures.

Accelerometers are electronic sensors which provide an accurate and precise way of measuring and storing the intensity, frequency, pattern, and duration of ambulatory physical activity. [30,83,110] Data from many accelerometers on the market are automatically processed by computer based programs provided by the manufacturer. After the signal from the accelerometer is filtered and amplified an analog voltage is converted to a digital series of numbers. The amplitude of this digital signal is the raw **activity counts**. Stated more simply, activity counts are a series of numbers representing the frequency and intensity of movement (vertical displacement) during the recording period of interest. Different analytical approaches are used to derive activity counts in different accelerometers (i.e. different amplification or analog to digital conversion factors). Therefore, despite the previously established validity and reliability of activity count data, counts are a dimensionless unit which can differ between brands and models with very little clinical meaning.

There is no direct physiological translation of activity counts to energy expenditure however laboratory studies suggest there is a linear relationship between counts per minute and energy expenditure. [103] This further permits investigators to determine the level or amount of exertion represented by an activity count. [50] Previous work has established regression equations to predict energy expenditure from the activity count data produced by accelerometers. For the Actigraph accelerometer alone, 15 equations have previously been published to estimate energy expenditure from activity counts during different activities (ie walking, running, cycling, activities of daily living). [114] Most all equations formulated have been developed by testing younger to middle aged healthy subjects [115] of normal weight. For instance, Freedson et al in 1998 formulated a model to predict energy expenditure from Actigraph activity counts per minute using oxygen consumption while 35 young to middle age adults (all in their 20's to 30's) walked on a treadmill at various set speeds. In this study, activity counts per minute and steady state oxygen consumption (mL/kg-min) were highly correlated ($r = 0.82$) and, during cross validation of the developed regression model in 15 subjects, no significant differences were revealed between actual and predicted energy expenditure. [101] To our knowledge, similar work has not been performed in older adults who may be more heterogenous in their walking speeds, functional abilities, and endurance compared to their younger adult counterparts.

The goal of this project was to further validate and explain what a processed "activity count" from the Actigraph accelerometer represents in our sample of community dwelling older adults (≥ 65 years of age). The specific aim for this project was to compare processed activity count data from the Actigraph accelerometer with 1) unprocessed magnitude of force data (G) from the BIOPAC accelerometer 2) oxygen consumption data and 3) pedometer step count data while older adult participants perform treadmill usual and slow walking tasks. Furthermore, we will compare Actigraph, BIOPAC, and oxygen consumption data within subjects across usual and slow treadmill walking conditions. We will also formulate a regression equation using Actigraph activity counts to estimate energy expenditure for adults over the age of 65 during treadmill walking. We will compare the newly developed energy expenditure equation for older adults to Freedson's equation to investigate if the two equations are different or similar in their ability to estimate energy expenditure in our sample of older adults. Specifically, we plan to compare the estimated energy expenditure using Freedson's equation to the actual energy expenditure measured during the usual and slow treadmill walking conditions in our study.

Our hypotheses are as follows: 1) For both usual and slow walking conditions a higher number of activity counts from the Actigraph accelerometer would be correlated with a larger magnitude of force (in G's) from the BIOPAC accelerometer, higher energy expenditure, and higher number of steps on the pedometer; 2) For usual versus slow walking conditions participants will have higher activity counts, a larger magnitude of force, and a higher energy expenditure; and 3) The regression equation estimating energy expenditure from activity counts formulated from this study will more precisely estimate actual energy cost in older adults than Freedson's equation previously tested in younger adults.

2.2 METHODS

2.2.1 Participants

Participants for this project included 30 ambulatory community dwelling older adults (Age 75.4 ± 4.4; 90% white; 67% female) recruited from the Claude D. Pepper Older Americans Independence Center Registry from Pittsburgh Pennsylvania and surrounding rural areas who were willing to travel into our research laboratory and were interested in mobility and balance studies (refer to TABLE 1 for further demographics). This center is one of nine National Institutes of Aging Centers of Excellence with a specific focus of reducing the frequency, severity, and consequence of mobility and balance disorders in older adults. Participants were excluded from the study if they were under 65 years of age, required assistance of another person or assistive device other than a cane to ambulate, if they reported an inability to ambulate a quarter of a mile (1320 ft) with rest breaks as needed, or if they had a neurodegenerative disease such as Multiple Sclerosis or Parkinsons. All subjects who participated in the study signed written informed consent and the study was reviewed and approved by the University of Pittsburgh Institutional Review Board.

Table 1 Participant demographics (N=29)

	Mean (SD) or Percentage (N)
Age	75.4 (4.4)
Race (% white)	90% (27)
Gender (% female)	67% (20)
Education (% college educated)	53% (16)
Living Arrangement (% living alone)	40% (12)
Marital Status (% married)	57% (17)
Fall History (% who had fallen in the past year)	43% (13)

2.2.2 Measures

2.2.2.1 Accelerometers

The participants wore two separate accelerometers during the testing session; one of the accelerometers provided processed activity count data (Actigraph) and the other provided raw acceleration data (BIOPAC SS26 Triaxial Accelerometer). Technical specifications and available data output of the Actigraph and BIOPAC accelerometers are provided in Table 2.

Table 2 Actigraph and biopac accelerometer specifications

	Actigraph	BioPac
Size	38 x 37 x 18 mm	33 x 28 x 19 mm
Weight	27 grams	17 grams
Recording period	182 days of activity + step count data 1 MB data storage	Continuous real time recording
Docking Station	USB charging and docking	N/ap
Case Protection	Water Resistant (not waterproof)	Water Resistant
Battery	3.7v Lithium-polymer rechargeable (14 days of charge)	No battery +5v @ 25 mA
Battery Re-charge Period	4 hours from full discharge	N/ap
Resolution	12 bit	N/ap
Sensor	Pizoelectric	MEMs technology (silicon micromachine)

2.2.2.1.1.1 Actigraph

The Actigraph accelerometer GTIM model (Actigraph, LLC, Fort Walton Beach, FL.) formerly known as the Computer Science and Applications (CSA) and Manufacturing Technology Inc.(MTI) is a small uniaxial monitor. (Refer to Figure 2) An acceleration signal is represented by an analog voltage which is sampled then digitized at a frequency range chosen to detect normal human motion and reject motion from other sources. The Actigraph monitor was charged, initialized and downloaded by a reader interface unit which was connected to the computer by a USB port. The monitor collects and reports activity counts in a certain epoch. An epoch is the time period in which the activity count data is presented and is a way to change the resolution or depth of detail in which you can view your data. At the end of each epoch, the activity count data is stored internally and the accumulator is reset to zero. According to the manufacturer, one activity count from the Actigraph accelerometer is equal to 4 milli Gs of gravitational force.

Figure 2 Actigraph GT1M Model

Inter-instrument and intra-instrument (test-retest) reliability of the Actigraph has been performed by comparing outputs from monitors worn on opposite hips during ambulatory tasks [89,92] and by using high precision shakers or turntable devices over multiple trials. [94,95] This reliability testing reveals intra-class reliability coefficients ranging from 0.40 to 0.99. Activity data from the Actigraph accelerometer has been validated in both laboratory and free living conditions against other makes and models of accelerometers,[96,97] self report measures,[96] doubly labeled water, indirect calorimetry,[79] and oxygen consumption (VO2)[59] with correlation coefficients ranging from 0.45 to 0.91. For our study, the goal was to collect Actigraph accelerometry data on all 30 participants. The Actigraph monitor was set to record activity counts in 1 second epochs (total activity counts per second). The activity counts were then averaged over the number of seconds spent in each walking condition (average activity counts per second). We also report activity counts per minute since this was the variable Freedson et al in 1998 used in their work.

2.2.2.1.1.2 BIOPAC

The BIOPAC accelerometer (SS26 Tri-Axial Accelerometer- Output +/- 5 g (400 mV/g) is a 5g accelerometer well suited for detecting slow movements such as walking. (Refer to Figure 3) The BIOPAC is a high level output transducer requiring no additional amplification. The accelerometer's pliable and unobtrusive design conforms to body contours. This accelerometer produces three simultaneous outputs measuring acceleration in the X, Y, and Z planes continuously. For the purposes of this study, only vertical acceleration (z plane) was of interest for comparison with the Actigraph accelerometer since the Actigraph is uniaxial and detects vertical acceleration only. Our goal was to collect BIOPAC data on a subsample of 20 people. To our knowledge, reliability and validity data has yet to be established on the BIOPAC accelerometer. Despite the lack of established psychometric properties, this accelerometer records magnitude of gravitational force data continuously in real time with the least amount of processing by the computer software programming provided by the manufacturer. The continuous data was taken at usable time intervals during each walking condition. During these time intervals, the offset of gravity (1 g) was removed. The derivative (change in acceleration over time) of the data was collected and the absolute value of this data was taken to make all changes positive. These positive changes in acceleration were then summed over one second intervals (sampled at 50Hz so 50 points summed per second).

Figure 3 BIOPAC Accelerometer

The accelerometers described above were attached to the waist by a belt clip or elastic belt dependent upon participants' preference. The monitors were securely fastened to the participant so that the monitors moved only when the participant moved and were not affected by extraneous factors. Specifically, the BIOPAC accelerometer was placed near the small of the participants' back and the Actigraph over the right hip near the anterior superior iliac spine. The waist, hip and low back locations have been shown to be well suited for picking up accelerations that occur during normal ambulatory movement [59,83,85] and yield the best prediction of energy expenditure.[85,86] The accelerometers were both small and lightweight so that the participants' walking or comfort level was not affected. The BIOPAC accelerometer was calibrated prior to each participants' testing session as recommended by the manufacturer (www.biopac.com provides directions for calibration). The Actigraph accelerometers were calibrated by the manufacturer after purchase. The same computer was used to initialize the Actigraph accelerometer and to collect the BIOPAC accelerometer data to insure time synchronization.

2.2.2.2 Pedometer

The Accusplit Eagle 120 Activity Pedometer (www.ACCUSPLIT.com San Jose, CA) is a spring-levered electronic activity monitor that is typically worn on the hip on a belt or waistband along the midline of the thigh and responds to vertical deflections of the hip, resulting in step counts(Refer to Figure 4). The Accusplit measures approximately 2 by 1.5 by 0.75 inches and weighs 0.75 ounces. It has been shown to be a valid and reliable assessment tool for assessing step counts in a variety of laboratory and field settings, [45,71,115-118] and it is one of the most commonly used tools to assess ambulatory activity in free-living situations. Several researchers have suggested that the pedometer is an appropriate method for measuring physical activity in those whose predominant behavior is walking. [68,119,120] However, data from pedometers have been shown to underestimate steps taken in those with slower gait speeds (ie, <0.9 m/s),[71-73] [29] irregular and unsteady gait patterns, [71,72,74-76] or obesity.[76,114] For this study, the Accusplit was worn on the participants' left hip near the anterior superior iliac spine. Our goal was to collect pedometer data on all 30 participants. Total pedometer step counts were recorded during the treadmill walking conditions. The pedometer was not reset between usual and slow walking conditions as a matter of safety for the participants since usual to slow walking was not separated by a rest break and we did not want to distract participants from their walking to reset the monitor.

Figure 4 Yamax Digiwalker Pedometer

2.2.2.3 Oxygen Consumption

Oxygen consumption (rate of oxygen uptake) is the gold standard for measuring energy expenditure of gait, [121] and assumed to represent all energy consuming body actions. [122,123] Steady state oxygen consumption is generally described by the flat (plateau) portion of the oxygen consumption curve. During steady state, the oxygen consumed is equivalent to the energy demand of the activity. At steady state, mean oxygen rate and energy cost were calculated by averaging the final 2 minutes of walking under both usual and slow walking conditions. Oxygen rate (mL/kg-min) is the amount of oxygen consumed per minute and reflects the intensity of sustained exercise. [124] At a comfortable walking speed, oxygen rate for older adults (60-80yrs) is 12.0ml/kg-min. [124] Energy cost (mL/kg-meter) describes the amount of energy used to walk a standard unit of distance. [124] Energy cost is a reflection of efficiency in walking a certain distance. At comfortable walking speed in older adults, average energy cost is 0.16 mL /kg-meter. [124]

Oxygen consumption was measured continuously using open circuit spirometry with computer-based data acquisition (Medgraphics VO2000® ambulatory metabolic measurement system for analysis of expired gases- Refer to Figure 5). The oxygen and carbon dioxide analyzers were calibrated according to the manufacturer's instructions before testing each participant. Participants were fitted with a neoprene elastic face mask (preVent mask) which covered their nose and mouth. A silicon adapter was used to secure the PreVent Pneumotach valve to the mask. The pneumotach valve was used to collected samples of the expired air. Expired air was collected and continuously analyzed for O2 and CO2 concentration. The changes in oxygen and carbon dioxide percentages in expired air were compared to the percentages of ambient air, indirectly reflecting the ongoing process of energy metabolism. In a sample of young adult males, Crouter et al in 2006 found good test- retest reliability of the V02000 metabolic system over a 48 hour period during stationary cycling (Pearson r = 0.983 to 0.989; coefficient of variation 8.8 to 15.8%). The portable Medgraphics VO2000 has been compared to the Medgraphics CPX/D metabolic systems (standard stationary method) and no differences were found in the measurement of VO2 and VCO2 between systems at rest {Olsen, 2003} or during cycle ergometry. [125] Our goal for this study was to collect oxygen consumption data on a sub-sample of 20 participants.

Figure 5 Medgraphics V02000 Metabolic System

2.2.2.4 Treadmill Walking

While wearing the accelerometers, oxygen consumption mask and pedometer the participants were asked to walk on the treadmill at their self selected usual and slow paces each for 4-5 minutes. The treadmill speeds were not pre-set because in our sample of older adults we were concerned not all would be able to maintain the same speed for an extended period. Also, we wanted to capture their usual comfortable walking speed not a speed foreign to them. A warm up period of 1-2 minutes was given prior to testing. Oxygen consumption data was collected for usual and slow walking conditions (from the initiation of warm-up until testing was complete).

In order to ensure accurate timing, the time on the computer which was used to initiate and download the accelerometers was synchronized with a digital wrist watch (Timex Ironman Triathlon 30 Lap) used to time the usual and slow treadmill walking conditions. A second by second journal was also kept by a research assistant during the testing session to document the time each walking condition and any rest breaks occurred. The total time for the testing session was between 30 minutes to 1 hour dependent upon participant fatigue and equipment set-up.

2.2.3 Statistical Analysis

Means, standard deviations and ranges were reported for all continuous variables. For oxygen consumption data, the oxygen rate (ml kg-1 min-1) was calculated by dividing the absolute oxygen consumption (ml min-1) by body mass in kilograms. The energy cost (ml/ kg-meter) was then derived by taking the oxygen rate and dividing it by the self selected walking speed on the treadmill (min/ meters) for the usual and slow conditions. The ratio of a person's working metabolic rate relative to the resting metabolic rate is defined as the metabolic equivalent (MET).

Absolute resting oxygen consumption divided by body weight provides the resting energy requirement of 1 MET.[126]The MET values for this study were calculated by dividing the steady state oxygen rate by the basal metabolic rate of a resting person (3.5 mL/kg-min).[126,127] One MET should represent the energy expended or metabolic rate of an individual at rest.[111]

A Pearson product moment correlation coefficient was calculated for each walking condition (usual and slow) to assess the association of Actigraph activity counts per second with 1) magnitude (g) of acceleration per second from the BIOPAC 2) oxygen rate and 3) energy cost of walking. Also, the correlation of Actigraph total activity counts during treadmill walking and pedometer step counts while on the treadmill was reported. Paired samples T tests were performed to determine the effect of walking condition (usual versus slow) on Actigraph counts per second, BIOPAC magnitude of force, oxygen rate, and energy cost.

In order to simulate Freedson's work in 1998, a linear regression was used to formulate an equation estimating the energy expenditure (METs and energy cost of walking) from Actigraph activity count per minute data for both usual and slow walking conditions. A paired samples T test was then used to compare within subjects differences between energy expenditure (METs) estimated from Freedson's equation with actual energy expenditure (METs).

2.3 RESULTS

Of the participants who had complete Actigraph data (N=29), 18 had BIOPAC data, 20 had oxygen consumption data and 28 had pedometer data. The mean gait speed participants walked on the treadmill for usual condition was 0.80 ± 0.21 m/sec or 1.8 ± 0.48 mph and for slow conditions was 0.6 ± 0.18 m/sec or 1.4 ± 0.41 mph. Therefore, our participants walked at speeds ranging from 0.5 to 1.2 m/sec for usual and 0.3 to 0.9 m/sec for slow conditions. Two of the participants reported fatigue during the treadmill walking and therefore only the usual walking condition was collected.

Actigraph activity counts per second were positively correlated with BIOPAC magnitude of force and negatively correlated with energy cost for both usual and slow walking conditions. (refer to Tables 3 and 4) The Actigraph counts per second were not correlated with oxygen rate or METs for usual or slow conditions. Total Actigraph counts during treadmill walking were not correlated with total pedometer steps accumulated while on the treadmill (Pearson $r = 0.15$; $p=0.44$; N=27). The paired samples T-test analysis revealed on average participants had higher Actigraph counts per second, higher BIOPAC magnitude of force per second and higher oxygen rate during the usual treadmill condition compared to the slow condition (See Table 5).

Table 3 Pearson correlation coefficients for usual treadmill walking condition

	BIOPAC mag/sec Usual (G)	Oxygen Rate (mL/kg-min)	Oxygen cost (mL/kg-meter)
Activity counts/sec Usual	**0.68**** N=18	-0.03 N=20	**-0.60**** N=20
BIOPAC usual		-0.9 N=11	-0.51 N=11
Oxygen rate			**0.65**** N=20

** $p \leq 0.01$/ * $p < 0.05$

Table 4 Pearson correlation coefficient for treadmill slow walking condition

	BIOPAC mag/sec Slow (G)	Oxygen Rate (mL/kg-min)	Oxygen cost (mL/kg-meter)
Activity counts/sec Slow	**0.51*** N=18	0.24 N=18	**-0.68**** N=18
BIOPAC slow		0.08 N=11	-0.59 N=11
Oxygen rate			0.35 N=18

**p≤0.01 / *p<0.05

Table 5 Mean accelerometer and energy expenditure data for usual and slow walking conditions

	USUAL	SLOW		
	Mean (SD) Range	Mean (SD) Range	T value	P value
Activity counts/sec N=27	21.1(11.0) 6.1 - 61.5	12.5 (6.7) 2.1 – 28.7	8.0	<0.001
BIOPAC mag in G/ sec N= 17	3.5 (1.5) 2.1 – 7.1	2.9 (1.0) 1.8 – 5.6	3.7	0.002
Oxygen rate (mL/kg-min) N=18	11.7 (2.1) 5.7 – 14.5	10.1 (1.9) 5.1 – 12.8	6.1	<0.001
Oxygen cost (mL/ kg -meter) N=18	0.27 (0.09) 0.1 - 0.49	0.31 (0.11) 0.19 – 0.55	-3.8	0.002

The linear regression equation for this study was formulated estimating the energy cost of walking from activity counts since those variables were highly correlated. Since Actigraph counts were not correlated with oxygen rate or METs, a linear regression equation to estimate these outcomes from Actigraph counts was not established. This differs from Freedson's previous work in 1998 in which activity counts per minute, oxygen rate and METS were highly related. This discrepancy made comparison between Freedson's equation to the newly established equation difficult since the two equations are estimating different components of oxygen consumption. Paired T-test analysis comparing estimated energy expenditure (METs) from Freedson's equation with actual energy expenditure (METs) revealed on average, Freedson's equation underestimated the actual METs measured by oxygen consumption for both usual (mean (SD) = 2.4 (0.58) vs. 3.2 (0.7) METs respectively; t= 4.0, p=0.001) and slow (2.0 (0.3) vs. 2.9 (0.55) METs respectively; t=6.6, p<0.001) walking conditions in our older adult subjects. We calculated an error score by subtracting the estimated MET values (Freedson equation for CPM) from the actual MET values (indirect calorimetry). A positive error value would indicate an underestimation by Freedson's equation and a negative value, an overestimation. We found the error score for usual walking to be 0.8 (0.9) METs. A one sample T-test revealed the error score was significantly different from 0 confirming an underestimation of METs by Freedson's equation (t = 4.0; p=0.001) during usual walking condition.

REGRESSION EQUATIONS ESTIMATING ENERGY COST FOR USUAL AND SLOW WALKING:

Energy Cost (mL/kg-meter) USUAL walking = 0.361 + - 0.000079 * counts/min usual

Energy Cost (mL/kg-meter) SLOW walking = 0.438 + -0.00018 * counts/min slow

2.4 DISCUSSION

Activity counts from the Actigraph accelerometer were positively correlated with the processed magnitude of force data from the BIOPAC accelerometer and negatively with energy cost in our older adult participants during usual and slow treadmill walking. Lower energy cost being related to higher activity counts may be due to the Actigraph accelerometer design to detect vertical acceleration at the waist. Lower energy cost equals more efficient walking. [124]

Participants whose hips, trunk and shoulders were more aligned in a vertical upright plane may be more likely to register higher counts per second in the same distance and speed walked since the accelerometer would be oriented in a more vertical direction on the waist. Poor posture could also affect normal respiration which would negatively affect energy cost making these participants less efficient walkers. [128]

Oxygen rate was not correlated with activity counts for usual or slow treadmill walking conditions in our sample of older adults which differs from previous findings in younger adult subjects [79,86,101]. However, older adults did have a higher oxygen rate and more activity counts during usual versus slow walking conditions confirming that both measures were able to distinguish a difference in activity intensity. It has been previously established that walking in younger and older adults can differ in certain characteristics. Several factors are known to be more prevalent in older adults versus younger during walking such as biomechanical abnormalities (i.e. lack of hip extension,[129,130] lack of heel strike,[131] forward flexed trunk [132] altered muscle activity and accessory motions[133-135] and/ or increased gait variability[136] (i.e. increased medial lateral or anterior posterior sway). Such changes have been demonstrated to affect the amount of energy older adults expended (oxygen rate),[137] and very well could have affected the performance of the older adults studied walking on the treadmill. However these changes may not have been detected by the Actigraph which again solely measures vertical accelerations at the waist.

Steps on the pedometer were also not correlated with total activity counts during the treadmill walking conditions. However, pedometer step counts were negatively correlated with body mass index (BMI) (Pearson r= -0.433; p=0.039; N=23). Also, our participants walked on average 0.8m/sec for their usual speed and 0.6m/sec for their slow speed. This supports that pedometers may underestimate steps taken in those with slower gait speeds (ie, <0.9 m/s),[71-73] [29] irregular and unsteady gait patterns, [71,72,74-76] or obesity.[76,138]

Usual walking speed on the treadmill produced more activity counts per second, higher magnitude of force, a higher oxygen rate and lower energy cost than slow walking in our participants. Also, at their self-selected usual speed, the average oxygen rate for our older adults was 11.7 which is comparable to the expected oxygen rate in older adults at their comfortable walking speed. [124] We did not set our older participants usual walking speed instead we allowed them to choose their own speed. Previously the desired usual walking speed for older adults has been reported as 1.2m/sec.[139,140] Our participants' usual walking speed on the treadmill was slower than usual gait speed for healthy older adults (1.2m/sec). [139,140] This may be a reflection of their overall health status, functional abilities or unfamiliarity with treadmill walking. For instance, the percent of participants in our study who had fallen in the past year was 43%. This is higher than the average fall rate for adults over the age of 65 which is 30%.[141,142] Therefore, our participants may have been lower functioning than the community dwelling older adults studied to decipher the usual preferred walking speed of 1.2m/sec.

Our design and results differed from Freedson's work in 1998 in that our participants were 1) older 2) walked at various speeds for their usual and slow walking conditions all of which were much slower than Freedson's set speeds and 3) had various body compositions. Specifically, the participants who were tested for oxygen consumption (N=20) had a mean body mass index of 30.1% . This classifies 25 % (N=5) as optimal weight (BMI 18.5 to 25), 25% (N=5) as overweight (BMI 25-30%) and 50% (N=10) as obese (BMI >30%). [143] As stated above, it was impossible to directly compare Freedsons' equation predicting oxygen rate or METs to our established equation predicting energy cost because the two equations are predicting two different measures of energy expenditure. In this study, activity counts were not at all correlated with oxygen rate or METs, so it did not make sense to establish a regression equation predicting these variables from activity counts per minute. We believe the difference stemmed from our participants walking at various self selected speeds whereas in Freedsons' study the walking speed was set. Since our participants walked at various speeds, the energy cost of walking is adjusted for their walking speed whereas the oxygen rate is not (the energy cost of walking variable is oxygen rate divided by the speed). In our participants, TM speed was correlated with Actigraph CPM for usual ($r=0.802$, $p<0.001$ $n=29$) and slow ($r=0.841$, $p<0.001$ $n=27$) walking conditions. This shows that the Actigraph CPM were sensitive to detecting the activity at various walking speeds chosen by participants in this study.

At a comfortable walking speed in older adults, the average energy cost has been reported as 0.16 mL/kg-meter.[124] In our sample at usual walking speed the average energy cost was 0.27mL/kg-meter. Also, according to the Compendium of Physical Activities, [43] walking less than 2.0 mph on level surface has a MET value of 2.0, walking at 2.0mph on level surface is 2.5 METs and walking at 2.5 mph on a firm surface was 3.0 METS. In our participants, those walking their usual pace at less than 2.0mph (N=11) had an average actual MET value of 3.3, those walking at 2.0mph (N=4) had a MET value of 3.5, and those walking at or above 2.1 mph had a MET value of 2.9. Therefore, the MET values in our older adult participants were higher compared to the Compendium's reported MET values for those given walking speeds. These discrepancies may be explained by the number of participants in our sample who were classified as obese (50%) or by potential biomechanical deviations which were not assessed in this study. Individuals who are obese expend much more metabolic energy during walking than normal-weight individuals. [144-146] Bloom and Marshall reported that the net metabolic rate of walking at speeds ranging from 0.7 to 1.4m/sec was approximately 45% greater in obese men and women compared to normal weight controls. [144] When an equation is developed in a particular age group, a range of body sizes should be included in the reference group. [147] While energy expenditure should be corrected for body size,[148] a single adjustment coefficient does not exist making it difficult to interpret results obtained from participants of different body sizes;[149]

To our knowledge this was the first study to collect two types of accelerometry data in addition to oxygen consumption data in a group of older adults during walking tasks. All of our subjects were able to tolerate the oxygen consumption testing on the treadmill for an average of 9 minutes. Previous equations predicting energy expenditure from accelerometers formulated for younger adults may very well not apply to older adult subjects. Future work is needed in a large sample of older adults during walking conditions to investigate the relation of energy expenditure with accelerometry output. Perhaps data from uniaxial accelerometers are not sufficient to predict energy expenditure in older adult subjects due to the many factors effecting energy expenditure and walking in this population. Studies comparing uniaxial versus triaxial accelerometry or multiple accelerometer placements in older adults should be completed to investigate if estimated energy expenditure improves.

Our study had several limitations. First, our regression equation developed for use in older adults was based on a small number of subjects and is only valid for treadmill walking activities. Therefore, this equation will not necessarily work well across a wide range of activities of daily living or overground walking in older adults. For instance, Leenders et al in 2000 has shown that Freedson's equation underestimates 24 hour physical activity energy expenditure by 59% versus doubly labeled water in young to middle aged adults. Future work testing both Freedson's equation and the equation presented in this project to predict energy expenditure from activity counts is necessary in older adults during overground walking tasks. This information would be clinically useful since many accelerometers are designed to be worn over extended periods of time during free living conditions. Also, we did not formally assess biomechanical abnormalities during walking in our older adult subjects. This would have been useful to identify if increased energy expenditure (oxygen rate) was higher in those with gait abnormalities potentially explaining the lack of correlation between Actigraph counts and oxygen rate. Finally, it would have been useful to provide all participants with treadmill walking practice sessions prior to the collection of oxygen consumption and activity data to ensure they were all comfortable and familiarized with treadmill ambulation.

Although many researchers view accelerometry as the preferred method for objectively measuring physical activity, some even considering it a criterion measure, accelerometer use is not without its challenges and unanswered questions. [50] We would recommend caution using prediction equations for energy expenditure which have been established in younger adults to predict energy expenditure of older adults from accelerometry data. A need exists to develop energy expenditure prediction equations for a larger sample of various older adults populations [i.e. those who are healthy and community dwelling, those living in supportive settings (assisted living, nursing home), those with chronic conditions] because their behavior may vary from that of younger adults due to changes in gait patterns, body compositions, and physiological processing that occur with aging. Also, our work focused on the Actigraph accelerometer count data but different accelerometer manufacturers have different standards for units of activity counts. [80] The count data is arbitrary and dependent upon the analog to digital converters, sensors and application factors which can differ based on the accelerometer manufacturer and brand.

3 INTER-RATER RELIABILITY AND KNOWN GROUPS VALIDITY OF ACTIGRAPH ACCELEROMETRY PHYSICAL ACTIVITY DATA WITH KNOWN FUNCTIONAL GROUPS IN COMMUNITY DWELLING OLDER ADULTS

3.1 INTRODUCTION

Accelerometers are electronic sensors which provide an accurate and precise way of measuring and storing the intensity, frequency, pattern, and duration of ambulatory physical activity.[30,110,150] Accelerometers have been validated in both laboratory and free living conditions and reliability has been established. [151-153] The typical default accelerometry output is activity counts, a measure of the frequency and intensity of vertical accelerations and decelerations. Despite the validity and reliability of activity count data, "activity counts" are a dimensionless unit which can differ between accelerometer brands and have very little clinical meaning. Compounding this problem, in addition to count data many accelerometers also provide further processed measurement units such as estimated number of minutes spent in various physical activity intensity levels, number of steps per minute, the estimated number of kilocalories, METS expended, or the number of bouts of activity. Inconsistencies exist in current literature as authors tend to present accelerometry data in various ways making comparisons between monitors and between measurement units extremely difficult. Psychometric properties have yet to be established for different models and brands of accelerometers for each unit of measurement the monitor can provide. For example, if an investigator plans to look at the number of 10 minutes bouts of physical activity a participant performs through the day, then reliability and validity of activity counts or kilocalories from that accelerometer does not support the psychometric properties which may be found for 10 minute bouts of activity.

The goal of this project was to establish inter-rater reliability and known groups validity against measures of mobility, performance based function, fear of falling, and self reported physical activity for the various measurement units of activity data from the Actigraph accelerometer. For this project, the measurement units from the Actigraph accelerometer included 1) activity counts per minute 2) variability of activity counts (standard deviation) 3) number of 5 minute bouts of activity 4) number of 10 minute bouts of activity and 5) number of minutes spent in moderate intensity activity. We hypothesized that inter-rater reliability (ICCs) will be high ($\geq$ 0.9) for each measurement unit of Actigraph activity data listed above. We anticipated that each of the Actigraph measurement units will be positively associated with mobility, performance based function, self-reported physical activity and negatively associated with age, fear of falling and self reported activity restriction. For known groups validity, we expected those participants who were classified as having better mobility and function would have higher activity counts per minute, greater standard deviation of activity counts, more 5 and 10 minute bouts of activity, and higher minutes of moderate intensity activity than those with lower mobility and function.

3.2 METHODS

3.2.1 Subjects

Participants for this project included 50 ambulatory community dwelling older adults with mobility disability (Age 76.8 ± 5.3 ; 86 % white; 64.2 % female). The participants who were able and willing to travel into our research laboratory were recruited from the Claude D. Pepper Older Americans Independence Center Registry from Pittsburgh Pennsylvania and surrounding rural areas (refer to TABLE 6 for further demographics). This center is one of nine National Institutes of Aging Centers of Excellence with a specific focus of reducing the frequency, severity and consequence of mobility and balance disorders in older adults. The participants recruited for this study were part of a randomized clinical trial of two different types of exercise intervention. Baseline participant data from the randomized clinical trial was used for this project. Participants were included in the study if they were 65 years or older and were able to walk without the help of another person or assistive device other than a cane. To be classified as having mobility disability participants were required to have a gait speed of ≤ 1.0 meters per second and exhibited gait variability (step length variability > 4.5% coefficient of variation [154] or step width variability of < 7% or ≥ 30% coefficient of variation. [155] Participants were excluded from the study if they had a neurodegenerative disease such as Multiple Sclerosis or Parkinsons, reported uncontrolled persistent lower extremity pain on most days of the week, had cognitive impairment (Mini-mental state examination score of <24), were hospitalized in the past 6 months for greater than 3 days, were hemiplegic or had a lower extremity amputation. All subjects who participated in the study signed written informed consent and the study was reviewed and approved by the University of Pittsburgh Institutional Review Board.

Table 6 Participant Demographics

	Mean (SD) or Percentage (N)
Age	76.8 (5.3)
Race (% white)	86 (44)
Gender (% female)	67 (34)
Education (% college educated)	37 (19)
Living Arrangement (% living alone)	41 (21)
Marital Status (% married)	51 (26)
Fall History (% who had fallen in the past year)	43 (23)

3.2.2 Measures

3.2.2.1 Physical Activity

3.2.2.1.1.1 Actigraph Accelerometer

The Actigraph accelerometer GTIM model [Actigraph, LLC, Fort Walton Beach, FL., formerly Computer Science and Applications (CSA) and Manufacturing Technology Inc.(MTI)] is a small pager sized uniaxial monitor. Uniaxial monitors record vertical acceleration in one plane. The Actigraph accelerometer can measure most types of physical activity that involve lower-extremity or trunk acceleration such as walking, running and stair climbing. An acceleration signal is represented by an analog voltage which is sampled then digitized at a frequency range chosen to detect normal human motion and reject motion from other sources. The Actigraph monitor was charged, initialized and downloaded by a reader interface unit which was connected to the computer by a USB port. Inter-instrument and test-retest reliability of the Actigraph has been established by comparing outputs from monitors worn on opposite hips during ambulatory tasks [89,92] and by using high precision shakers or turntable devices over multiple trials. [94,95] Activity data from the Actigraph accelerometer such as activity counts, estimates of energy expenditure and step counts has been validated in both laboratory and free living conditions against other makes and models of accelerometers,[96-98] self report measures,[96] doubly labeled water, indirect calorimetry,[79]and oxygen consumption.[59]

Actigraph activity data was set to record in one minute epochs over 7 consecutive days while the participants performed their habitual daily activities. An epoch is the time period in which activity data is presented providing a way to change the resolution or depth of detail in which you can view your data. For instance, if you set a one minute epoch, you can view your activity count data each minute where as a one second epoch will allow you to view your count data every second. One minute epochs are commonly used in investigating activity count data in adults. [80] Previous research revealed that for adults, 3 to 5 days of monitoring is required to reliably estimate the measurement outcome variables typically used in accelerometry studies. [42,87,88] Therefore, we excluded participant data if they did not wear the accelerometer for at least 3 days.

We distributed the accelerometers to participants on a face to face basis to ensure participants were briefed about the care and use of the monitor. [83] The research staff verbally instructed and physically demonstrated to the participants the placement of the accelerometer; on the waist aligned with the midline of the right thigh. It makes little difference whether the monitor is worn on the right or left side but it is important to have a standard protocol suggesting that one side be used consistently.[50] Positioning on the waist, hip or low back are well suited for picking up accelerations that occur during normal ambulatory movement [59,83-85] and have been shown to yield the best prediction of energy expenditure.[85,86] We provided the participants with a 7 day activity journal asking them to record 1) the time the monitor was put on in the morning 2) the time the monitor was removed at night and 3) any time during the day that the monitor was removed for greater than a 30 minute period (i.e. to shower, swim, for MD appointments requiring X-rays or MRIs). The participants were asked to keep the monitor on until they were ready to fall asleep as to avoid premature removal of the monitor. In previous work, it has been noted that participants often remove the monitor near the time of sleep but remain awake for minutes to hours (i.e. reading or watching television) before they actually fall asleep.[156] We considered 8 hours of wear time to signify a full day (if a participant wore the monitor for less than 8 hours that day was not included).[157,158] The participants were given an information reminder front sheet for accelerometer use as well as a cell phone contact number of a research staff member who would be available 7 days per week to address questions and concerns. Finally, a manual of procedures (MOP) for visually inspecting and analyzing each measurement unit of the Actigraph data was created as a concerted effort by two research staff members. The MOP included regularly encountered problems and frequently asked questions with corresponding solutions (activity journal and MOP available upon request).

Actigraph Accelerometer Measurement Units

Activity counts per minute (CPM)

According to the Actigraph manufacturer, one activity count is equal to 4 milli G's per second and should be linearly related to the intensity of the partcipants' physical activity during that interval of time. Comparing oxygen consumption to one minute epochs of Actigraph data in healthy younger adults while walking on a treadmill, the following activity levels based were established: [101]

Light activity: ≤ 1952 counts (< 2.99 METS)

Moderate activity: 1953 to 5724 counts (3.0 to 5.99 METS)

Strenuous activity: 5725 to 9498 counts (6.0 to 8.99 METS)

Very Strenuous activity: > 9498 counts (> 9 METS)

For our study, activity counts were summed for each day the participant wore the monitor (activity counts per day). This activity count value was then divided by the number of minutes worn for each day (activity counts per minute). Finally, the activity counts per minute for each day were averaged over number of the days worn (average activity counts per minute).

Variability of Activity Counts (SD)

It has been speculated that analyzing the variability of accelerometer activity count data between several successive epochs may provide closer estimates of energy expenditure than using counts alone. [114] Walking and running are rhythmic locomotor physical activities which produce highly consistent acceleration activity counts across time. Lifestyle activities such as gardening, vacuuming, sweeping, ironing are intermittent with more minute to minute variation in activity counts than walking.[80,99] We investigated variability of activity counts by calculating the standard deviation of activity counts per minute averaged over the participants' days of wear (average standard deviation of activity counts).

5 and 10 minute bouts of activity

In addition to the total duration and amount of physical activity in a day, the number and length of bouts in which physical activity occurred should be assessed. [50] An activity bout was operationally defined for the purposes of this study as a period of time in which activity count data does not fall to zero for a one minute epoch. Therefore, a 5 and 10 minute bout of activity were 5 and 10 minutes respectively of continuous activity count data without any minute periods of zero count data. The number of bouts of activity were summed for each day the participant wore the monitor then divided by the days of wear (average bouts of activity)

Minutes of Moderate Intensity Physical Activity (min mod)

Data from accelerometers allow researchers to quantify the amount of time an individual spends in light, moderate and vigorous physical activity.[138] The Surgeon General recommends 30 minutes of moderate-intensity activity on most, if not all, days of the week for adults to be physically active and achieve health benefit.[24] The Surgeon General's recommendation is comparable to expending approximately 150 kcal of energy per day[24] for an otherwise healthy individual whose principal mode of activity is walking. Using the Freedson's equation in the programming provided by the Actigraph manufacturer, the participants' weight in pounds was entered and the number of minutes spent in moderate intensity activity each day was calculated and averaged over the days of wear (average min of mod activity).

3.2.2.2 Mobility

3.2.2.2.1.1 Short Physical Performance Battery

Using measures of standing balance, gait speed and chair rise capacity, the SPPB is a performance test to assess lower extremity function and mobility. [159] Standing balance assessment involved side by side, semi-tandem, and tandem stance for 10 seconds each. Gait speed was assessed walking 4 meters from a standing start instructing the participants to walk at their usual pace with the faster of the two trials used. Participants were then asked to stand and sit from a chair 5 times as quickly as they could with arms across their chest. Each test was scored on a 0 to 4 point ordinal scale with summary performance scores ranging from 0-12 (higher scores = better performance). Scores obtained from the SPPB have been shown to be predictive of subsequent disability, institutionalization, and death. [159,160] Using a SPPB cut off score of 10 we dichotomized our participants into high (≥ 10) and low (<10) mobility groups. Compared to participants scoring 10-12, Guralnik et al in 2002 found those scoring 4-6 were 3 to 5 times more likely to experience mobility disability and those scoring 7-9 were 1.5 to 2 times more likely. [160]

3.2.2.3 Function

3.2.2.3.1.1 Physical Performance Test (PPT)

The 7 item PPT test is used to assess multiple domains of physical function by asking participants to perform tasks meant to simulate activities of daily living (i.e. writing a sentence, turning 360 degrees, putting on and removing a jacket, walking 50ft). Scoring for each task is based on an ordinal scale 0 “unable to perform” to 4 “fastest or best performance”. The total 7-item PPT score ranges from 0-28 with higher scores indicating better function. In a sample of 179 older adult subjects from various residences (i.e. community dwelling to nursing home) the 7- item PPT was found to be reliable (inter-rater Pearsons r=0.93; Cronbach’s alpha = 0.79) and demonstrated concurrent and construct validity with other measures of function and health. [161] Scores on the PPT were found to be moderately to highly correlate with instrumental and basic activities of daily living scales, Tinetti gait score, self reported health status, cognition, mental health and age. [161] Physical activity and physical function can be considered reciprocal determinants since activity helps maintain function and inactivity increases the risk of functional decline [162,163] Previous work in 179 older adults from 6 different residential settings established 10^{th}, 25^{th}, 75^{th} and 90^{th} percentile scores of the 7 item PPT. [161] Using a 7 item PPT cut off score of 22/28, representative of the 75 percentile score, participants were dichotomized into high (≥

22) and low (<22) functioning groups. We chose the 75th percentile score to avoid having too few participants in a functional group which was the case when choosing previously established 10th and 25th percentile scores.

3.2.2.4 Fear of Falling

3.2.2.4.1.1 Survey of Activities and Fear of Falling in the Elderly (SAFFE)- fear component

The SAFFE is an interviewer administered instrument for measuring physical activity, activity restriction and fear of falling in basic and instrumental indoor and outdoor activities of daily living.[164] The SAFFE fear subscale is based on a 4 point rating scale (0= not worried, 1= a little worried, 2= somewhat worried, 3 very worried) requiring the participants to judge how worried they are about falling during 11 specific activities (i.e. preparing simple meals, taking a tub bath, going to a place with crowds). The fear subscale is calculated by summing the fear values associated with each activity and then dividing by the number of activities they actually perform. Internal consistency reliability for the 11-item fear scale was 0.91 [164]. The SAFFE has been validated against the Activity Specific Balance Confidence Scale, Berg Balance Scale, and SF-36 subscales.[164,165] The fear of falling subcomponent has been associated with activity restriction and avoidance. [164,166]

3.2.2.5 Self Reported Physical Activity

3.2.2.5.1.1 SAFFE activity and activity restriction components

The SAFFE- activity subscale surveys participation in 11 specific physical activities (i.e. Do you currently go to the store- yes or no). The score (range 0-11) represents the number of activities out of 11 which participants currently perform. SAFFE activity restriction is gauged by asking the participants whether they do the 11 specific activities more, the same or less frequently than they did 5 years ago. The restriction subscale is calculated by summing the number of activities of 11 which they report having been done less over the past 5 years.

3.2.3 Statistical Analysis

All statistical analysis was performed using version 15.0 SPSS software (SPSS Inc. Chicago IL). Descriptive statistics (means, standard deviations and ranges) were reported for all variables of interest. Inter-rater reliability was performed by two research assistants both of which had approximately 2 years of experience using the Actigraph accelerometer. The research assistants were masked to the others recordings. Using the default Microsoft Office Excel (version 2007) spreadsheet of Actigraph activity count output, both investigators removed the activity counts for the times the participants reported not wearing the monitors during the 7 days of recommended wear. For 17 randomly chosen participants, the raters independently analyzed by visual inspection the number of 1) CPM 2) SD of activity counts 3) 5 min bouts and 4) 10 min bouts for each day of monitor wear. Inter-rater reliability was not calculated for minutes of moderate intensity activity since the Actigraph accelerometer software calculates this value. This analysis took each rater approximately 45 to 60 minutes per participant. Intra class correlation coefficients (ICC) were used to establish inter-rater reliability. We estimated the between and within subjects variability for each measurement unit of interest in order to compute the ICC values.

A Pearsons product moment correlation coefficient was used to assess the association of each Actigraph activity measurement unit (CPM, SD, 5 min bout, 10 min bout, min mod) with each other as well as with mobility, physical function, fear of falling, self reported physical activity measures and age. Next, 2 by 2 analysis of variance were performed on each average Actigraph measurement unit of interest as a function of mobility (SPPB: high vs. low) and physical function (PPT: high vs. low). Since there are 5 Actigraph measurement units of interest, 5 different 2 by 2 ANOVAs were constructed. A p value of ≤ 0.05 (2 tailed) was considered a significant effect.

Finally, receiver operator characteristic (ROC) curves were analyzed with the goal of identifying Actigraph activity data cut off values to detect mobility problems and physical function difficulties. In previous, current and future research using Actigraph accelerometry, cut off values for mobility and physical functioning difficulties adds meaning to the measure. Since physical therapy intervention is often focused on promoting independent mobility and functioning, we felt using an Actigraph activity data cut points to identify these problems makes clinical sense. Specifically, a positive test for the ROC curve was the presence of mobility problems (SPPB <10) or physical function difficulties (PPT < 22). We wanted to choose the most highly sensitive activity cut off value with acceptable specificity to reduce the number of false negative test results (people identified as not having mobility or function problems when they actually do). Since interventions such as physical therapy, community fitness, and wellness programs (i.e. silver sneakers) that address mobility and physical function are not intrusive or unreasonably expensive it is important to identify everyone with the problem while accepting you may treat a few people identified as having the problem who actually do not. The Actigraph measurement unit with the most acceptable reliability and know groups validity was be used to create the ROC curves.

3.3 RESULTS

Complete Actigraph data was collected on 48 of 50 participants. Of the missing data, one participant refused to wear the monitor because of burden (the monitor kept falling off of his belt) and the other accelerometer failed during recording. The average wear time per day for the participants was 14.3 hours (857.6 ± 95.8 minutes). The days of actual wear ranged from 3 to 7 with an average of 6.75 ± 0.79 days. On average, the majority of participants were grouped into low mobility (60%; n=29) and low function (65% n=31) groups. Descriptive statistics for all the Actigraph measurement units, mobility, function, fear of falling and self-reported activity are presented in Table 7.

Table 7 Mean Actigraph Outputs, Mobility, Performance, Activity, and Fear of Falling Measures for the Entire Group of Community Dwelling Older Adults

	Mean (SD)	Range
Activity CPM	132.3 (63.1)	21.3 to 315.3
SD of Counts	288.0 (114.2)	79.0 to 598.8
5 Min. Bouts	24.1 (5.6)	6.4 to 38.0
10 Min. Bouts	11.4 (4.0)	2.6 to 21.3
Min. of Moderate Intensity	5.0 (5.8)	0 to 23.4
Gait Speed (m/sec)	0.9 (0.15)	0.5 to 1.2
SPPB scores	8.7 (2.0)	3 to 12
7-item PPT	20.4 (2.7)	14 to 26
SAFFE fear of falling	0.6 (0.46)	0 to 2
SAFFE activity	8.3 (1.5)	5 to 11
SAFFE activity restriction	3.5 (2.7)	0 to 10

The intra class correlation coefficients for each of the measurement units of interest on 17 participants were all greater than 0.99 All Actigraph data measurement units were moderately to highly correlated [167] with one another (Pearson correlation coefficient r = 0.327 to 0.89; p < 0.03 in all cases). (See Table 8) Additionally as expected, all Actigraph measurement units, with the exception of 5 minute bouts, were positively correlated with mobility (SPPB scores), function (PPT scores), self reported physical activity (SAFFE –activity subscale) and negatively correlated with age. The Actigraph output of 5 minute bouts was moderately correlated with SPPB scores, PPT scores, and age only. None of the Actigraph measurement units were correlated with fear of falling or activity restriction. (See Table 9 for further details)

Table 8 Pearson Correlation Coefficients of Actigraph outputs with each other

	SD of counts	**10 min bouts**	**5 min bouts**	**Min mod intensity**
CPM	**0.89****	**0.78****	**0.58****	**0.75****
SD of counts		**0.58****	**0.43****	**0.89****
10 min bouts			**0.85****	**0.47****
5 min bouts				**.33***

** p<0.01 / *p<0.05

Table 9 Pearson correlation coefficients with Actigraph outputs

	Average Actigraph Outputs				
	CPM	**SD of counts**	**10 min bouts**	**5 min bouts**	**Min. of Mod. Intensity Activity**
Age	**-0.52****	**-0.48****	**-0.38****	**-0.31***	**-0.32***
SPPB scores	**0.51****	**0.52****	**0.39****	**0.36***	**0.36***
7 item PPT scores	**0.55****	**0.56****	**0.48****	**0.35***	**0.48****
SAFFE- fear	0.07	0.16	-0.001	-0.04	0.10
SAFFE- activity	**0.45****	**0.50****	**0.35***	0.22	**0.40****
SAFFE- act. Restrict	-0.07	-0.13	-0.24	-0.26	-0.06

**p<0.01/ *p<0.05

All Actigraph activity data was normally distributed (Shapiro Wilk test p >0.05) and met the assumption of homogeneity of variance (Brown Forsythe test p>0.05) for both mobility and function groups except minutes of moderate intensity activity. Minutes of moderate intensity activity violated the assumption of normality (Shapiro Wilk p <0.05), it was positively skewed.

All other assumptions (i.e. independence or subjects, absence of outliers) were met. The various ANOVA results revealed mean differences in the Actigraph measurement units of activity CPM and SD of activity counts based both on mobility and physical function performance groups. Participants who were classified into the high mobility and/ or high function groups had significantly more CPM and higher SD of activity counts compared to those in the less mobile and/or low function groups. Participants classified into the high mobility group also had higher 5 minute bouts compared to those in the low mobility group but this relation did not exist for functional groups. The Actigraph measurement units of 10 minute bouts and minutes of moderate intensity activity were not able to discriminate between mobility or functional groups. Please refer to Tables 10 and 11 for further details.

Table 10 Mean Actigraph measurement units by short physical performance mobility groups

	Mobility		
	High (≥10) N=19	**Low (<10) N=29**	**F (P value)**
Activity CPM (95% CI)	**164.5 ± 12.8 (138.7-190.3)**	**122.8 ± 11.6 (99.4-146.2)**	**5.8 (0.02)**
SD of Counts (95% CI)	**344.5 ± 23.2 (297.8- 391.3)**	**273.2 ± 21.0 (230.9-315.4)**	**5.2 (0.03)**
10 Min. Bouts (95% CI)	13.1 ± 0.8 (11.4 - 14.8)	11.0 ± 0.8 (9.5 - 12.6)	3.4 (0.07)
5 Min. Bouts (95% CI)	**26.8 ± 1.2 (24.4 – 29.2)**	**22.9 ± 1.1 (20.8 - 25.1)**	**5.6 (0.02)**
Min. of Mod. Intensity	7.3 ± 1.3 (4.8 – 9.9)	4.4 ± 1.1 (2.1 - 6.7)	3.0 (0.09)

Table 11 Mean Actigraph measurement units by physical performance functional groups

	Function		
	High (≥ 22) N= 17	**Low (<22) N = 31**	**F (P value)**
Activity CPM (95% CI)	**165.8 ± 13.6 (99.9 - 143.1)**	**121.5 ± 10.7 (138.5-193.2)**	**6.7 (0.01)**
SD of Counts (95% CI)	**348.2 ± 24.5 (298.8 – 397.6)**	**269.5 ± 19.4 (230.4 - 308.6)**	**6.3 (0.02)**
10 Min. Bouts	13.2 ± 0.9 (11.4-15.0)	10.9 ± 0.7 (9.5-12.3)	4.1 (0.05)
5 Min. Bouts	25.5 ± 1.3 (22.9-28.1)	24.2 ± 1.0 (22.2- 26.2)	0.62 (0.43)
Min. of Mod. Intensity	7.5 ± 1.3 (4.9 – 10.2)	4.2 ± 1.0 (2.1 – 6.3)	3.9 (0.05)

Activity CPM was used as the Actigraph data output to construct the ROC curves. The CPM variable was the default output which the manufacturer reports has the least amount of error. The CPM exhibited high inter-rater reliability and moderate to high correlations with the measures used to validate the Actigraph. Furthermore, activity CPM was able to discriminate between high and low mobility and functional groups. The ROC curve to predict mobility problems using Actigraph activity CPM cut points had an area under the curve of 0.73 ± 0.07 (95% CI 0.58 to 0.89) indicating a clinician could properly identify a participant with mobility problems 73% of the time using activity counts per minute. With a cut off value of 149.5 CPM, the sensitivity of detecting mobility problems was 76% with a specificity of 63%. The ROC curve to predict functional problems was very similar to that of mobility problems; area under the curve of 0.73 ± 0.08 (95% CI 0.58 to 0.88). Again with a cut off value of 149.5 CPM, the sensitivity of detecting physical functioning problems is 71% with a specificity of 59%. Refer to Table 12 and 13 for additional Actigraph CPM cut off values.

Table 12 ROC Actigraph CPM cut point values for detecting mobility problems

Actigraph CPM Cut Off Values	Sensitivity	Specificity
122.4	59%	68%
149.5	**76%**	**63%**
170.0	83%	47%
189.3	90%	26%

Table 13 ROC Actigraph CPM cut point values for detecting physical function problems

Actigraph CPM Cut Off Values	Sensitivity	Specificity
121.0	58%	77%
149.5	**71%**	**59%**
177.5	87%	53%
195.0	94%	29%

3.4 DISCUSSION

As expected, physical activity data from the Actigraph accelerometer was found to have high inter-rater reliability and correlated well with measures known to be associated with physical activity. Participants with higher activity recordings from the Actigraph had better mobility, better functioning, more self-reported activity, and were younger than their less active counterparts. Actigraph activity CPM and SD of counts were the only data outputs that were able to discriminate between participants classified into the low and high mobility AND functional groups based on previously established population means. Actigraph activity cut points may be able to highlight those participants/ patients who have mobility and or functional problems. With a cut off value of approximately 150 CPM over the course of a week, an investigator can be fairly certain (over 70%) that they are identifying those who may have mobility and functional issues if activity CPM fall below this value. Davis et al in 2007 investigated Actigraph physical activity in >150 healthy community dwelling older adults (mean age = 76.1) in the United Kingdom over 7 days during waking hours recording in one minute epochs. The authors found daily mean counts per minute to be 245.8 (91.5) for their participants compared to our mean daily counts per minute of 132.3 (63.4) for participants with mobility disability.

We were interested by the lack of correlation between measures of fear of falling with physical activity as measured by the Actigraph. The SAFFE –fear component scores for our participants ranged from 0-2 with a mean of 0.56. Previous work has identified scores of ≤ 0.4 to indicate no fear, > 0.4 to <.95 as fear without restriction, and ≥ 0.95 to be fearful with activity restrictions. [164,168] Therefore, we did have participants who would be classified as fearful in our group. The lack of correlation may be further explained by our sample of community dwelling older adults many of whom were independent dwellers or had spouses which required some degree of care. Even though these older adults were fearful perhaps they were not willing to sacrifice their independence in living due to the fear. For instance, in order to remain independently community dwelling, many older adults despite fear still are required to go grocery shopping, do laundry, travel to physician appointments, perform cooking and do household chores. Also, one could argue that an older adult who is able to sample many different activities because they are more physically active may better be able to gauge their fear than someone who has restricted their activity.

SAFFE activity restriction was also not correlated with any Actigraph physical activity measurement units. The SAFFE activity restriction subscale asks older adults if they do the 11 specific activities less than they did 5 years ago. Therefore, this is relative to the participants' previous physical activity which may be subject to recall bias. Also physical activity and activity restriction are two different concepts. For instance, you may have a participant who has done very little physical activity throughout his/her life. This person therefore would not be restricted compared to 5 years ago, instead they would just be inactive.

Our study had several strengths. This is one of the first studies to our knowledge where all Actigraph accelerometry activity outputs were compared in community dwelling older adults with mobility disability. Most of the previous studies in Actigraph accelerometry have been performed in younger to middle aged adults. We formulated a manual of procedures, participant activity journal and information front sheet to promote compliance with accelerometer wear. Despite its importance, the topic of compliance has received very little attention in the research literature and no experimental studies investigating the efficacy of different strategies to improve compliance have been completed. [50,83] Trost in 2005 recommends additional compliance strategies such as 1) make reminder phone calls 2) provide participants with tips or lists of frequently asked questions 3) display written materials on bulletin boards or refrigerators to prompt wearing the monitor 4) show participants an example of output to show that you can tell when they are not wearing them and 5) provide incentives contingent on compliance. Also, our participants wore the accelerometers on average 6.8 days which incorporated both habitual weekend and weekday activities. As stated above, test –retest reliability improves with increased days of wear.[83, 84] Finally, we only had 4% missing data (2/50) and no accelerometers were lost even though our participants were taking the accelerometers into their homes and community for 7 days or more.

Our study had several areas of weakness. First, in calculating the minutes of moderate intensity activity, it has been reported that Freedson's equation tends to overestimate sedentary behaviors, light intensity activities and walking and may underestimated many moderate intensity lifestyle activities such as climbing stairs. [169]Also, previous equations established to estimate energy expenditure from the Actigraph accelerometer have predominately been performed in younger to middle aged healthy adults in laboratory settings. Future investigation and validation of the Actigraph accelerometer with energy expenditure in older adults needs to be completed since the type, frequency, and response to activities in older adults may differ compared to that of younger adults. Second, some authors have recommended identifying each Actigraph monitor with a number and then using the ID number as a covariate to control for unwanted error due to monitor variability.[50,147] We did not control in our analysis for the monitor each participant was wearing.

Many researchers view accelerometry as the preferred method for measuring physical activity however its use is not without its challenges. There remains a lack of understanding of how the monitors function, standards of wear and compliance, how to interpret manipulate and analyze the data provided. [50] We hope our work further establishing the inter-rater reliability and validity of Actigraph accelerometry data in older adults helps to address and minimize these challenges.

3.5 CONCLUSIONS

The Actigraph accelerometer measurement units all exhibited high inter-rater reliability and were validated against measures of mobility, function and self-reported physical activity in this sample of community older adults. Meaningfulness of activity count data was addressed by establishing activity counts per minute cut points to identify mobility and functional difficulties. Despite these results, there remains a pressing need for standardized accelerometry data reduction and analysis. Making decisions and stating clearly how the data will be cleaned, collapsed, and analyzed before data collection begins will allow increased comparison among studies once they have been published.[50]

4 RESPONSIVENESS OF ACTIGRAPH ACCELEROMETRY PHYSICAL ACTIVITY DATA WITH EXERCISE INTERVENTION IN COMMUNITY DWELLING OLDER ADULTS

4.1 INTRODUCTION

Health care professionals often take measurements at initial evaluation and at subsequent time points during treatment to detect a clinically meaningful change in the outcomes of interest. In assessing change, the ultimate goal is to distinguish between groups of patients who have improved, deteriorated or remained stable. [170] Responsiveness can be described as the ability to detect a clinical change [171] and is a component of validity. [172] Hays and Hadorn in 1992 stated "Validation is an ongoing process of obtaining multiple sources of information and empirical evidence to assess whether the instrument actually measures what it purports to. Each piece of evidence including the instruments responsiveness provides important information about the validity of a measure."

Accelerometers are electronic sensors which provide an accurate and precise way of measuring and storing the intensity, frequency, pattern, and duration of ambulatory physical activity.[30,110,150] Accelerometers have been validated in both laboratory and free living conditions and intra instrument and test re-test reliability has been established. [151-153] The feasibility of using accelerometers in the clinical setting to measure habitual physical activity may increase since the cost of the monitors continue to decrease. Despite their frequent use, meaningful change values and responsiveness of accelerometry data with exercise intervention has yet to be established. Furthermore, most of the reliability and validation accelerometry studies to date have focused on young to middle aged adults; little has been performed in older adult populations. With potential increased use of accelerometers in clinical and research settings, investigators will need a criteria to determine if a change in accelerometry based physical activity for their patients is clinically meaningful. Meaningful change values for accelerometry based physical activity could assist in planning and comparing the effectiveness of various interventions geared toward improving physical activity. For these interventional trials, defining meaningful change in accelerometry based physical activity can assist in calculating sample size, reporting those who could benefit from the intervention and estimating the number needed to treat. [173] Therefore, research involving accelerometry based physical activity is needed to explore analysis of intra-individual change in accelerometry output over time, the magnitude of this intra-individual change necessary to establish clinical relevance, and methods to link statistical analysis to clinically meaningful change standards. [174]

Physical function and mobility based measures used at baseline in clinical practice or research are valuable to discriminate future health and function in older adults. [159] Physical therapy interventions are often designed with the goal of improving physical function and promoting independent mobility in those with physical performance or mobility difficulties. In previous work, it has been established that physical activity, mobility, and physical function are related constructs. [123, 110, 111] For instance, physical activity and physical function can be considered reciprocal determinants since activity helps maintain function and inactivity increases the risk of functional decline [162,163] Specific to the older adult population, meaningful change values and responsiveness have been established for various physical function and mobility measures (ie. 6 minute walk test, gait speed, Short Physical Performance Battery). [173]

The purpose of this study was to estimate magnitude of meaningful change scores for the Actigraph accelerometer physical activity output. Additionally, since physical activity, mobility and function are known to be related, our secondary purpose was to investigate if changes in accelerometry based physical activity were present in a group of subjects expected to improve in mobility and function over time in response to a mobility intervention program. We expected that the participants who improved in mobility (Gait speed) and performance based function (Physical Performance Test scores) after the 12 week exercise program would exhibit the greatest increase in accelerometry based physical activity followed by those who have not changed then lastly those who had worsened in their mobility and function.

4.2 METHODS

4.2.1 Participants

Participants for this project included 50 ambulatory community dwelling older adults with mobility disability (Age 76.8 ± 5.3 ; 86 % white; 64.2 % female). See Table 14 for further demographic information. The participants were recruited from the Claude D. Pepper Older Americans Independence Center Registry from Pittsburgh Pennsylvania and surrounding rural areas who were able and willing to travel into our research laboratory (refer to TABLE 1 for further demographics). This center is one of nine National Institutes of Aging Centers of Excellence with a specific focus of reducing the frequency, severity, and consequence of mobility and balance disorders in older adults. Participants were included in the study if they were 65 years or older and were able to walk without help of another person. To be classified as having mobility disability the participants were included if they had a gait speed of $\leq$ 1.0 meters per second, and exhibited gait variability (step length variability > 4.5% coefficient of variation [154] and step width variability of < 7% or $\geq$ 30% coefficient of variation). [155] Participants were excluded from the study if they had a neurodegenerative disease such as Multiple Sclerosis or Parkinsons, reported uncontrolled persistent lower extremity pain on most days of the week, had cognitive impairment (mini-mental state examination score of <24), were hospitalized in the past 6 months for greater than 3 days, hemiplegic, or had a lower extremity amputation. The participants recruited for this study were taking part in an exercise intervention trial lasting 12 weeks (2 times a week for 12 weeks). The exercise intervention consisted of stretching, static and dynamic balance exercises, walking and strengthening. The primary goal of this intervention was to improve mobility. We used baseline and 12 week follow-up data to investigate changes in mobility against changes in Actigraph output for each participant in the study. Further description of the exercise intervention is available upon request. Written medical approval/clearance was obtained from the participants' physician to participate in low to moderate intensity supervised activity as is characteristic of the interventions for improving gait. All subjects who participated in the study signed written informed consent and the study was reviewed and approved by the University of Pittsburgh Institutional Review Board.

Table 14 Participant Demographics

	Mean (SD) or Percentage (N)
Age	76.8 (5.3)
Race (% white)	86 (44)
Gender (% female)	67 (34)
Education (% college educated)	37 (19)
Living Arrangement (% living alone)	41 (21)
Marital Status (% married)	51 (26)
Fall History (% who had fallen in the past year)	43 (23)

4.2.2 Physical Activity Measure

4.2.2.1 Actigraph Accelerometer

The Actigraph accelerometer GTIM model [Actigraph, LLC, Fort Walton Beach, FL., formerly Computer Science and Applications (CSA) and Manufacturing Technology Inc.(MTI)] is a small pager sized uniaxial monitor. Uniaxial monitors record vertical acceleration in one plane. The Actigraph accelerometer can measure most types of physical activity that involve lower-extremity or trunk acceleration such as walking, running and stair climbing. Inter-instrument and test-retest reliability of the Actigraph has been established by comparing outputs from monitors worn on opposite hips during ambulatory tasks [89,92] and by using high precision shakers or turntable devices over multiple trials. [94,95] Activity data from the Actigraph accelerometer has been validated in both laboratory and free living conditions against other makes and models of accelerometers,[96-98] self report measures,[96] doubly labeled water, indirect calorimetry,[79]and oxygen consumption.[59]

The default data output of the Actigraph with the least amount of error or processing is activity counts. According to the Actigraph manufacturer, one activity count is equal to 4 milli G's and should be linearly related to the intensity of the partcipants' physical activity during that interval of time. Comparing oxygen consumption to one minute epochs of Actigraph data in healthy young adults while walking on a treadmill, the following activity levels were established: [101]

Light activity: ≤ 1952 counts (< 2.99 METS)

Moderate activity: 1953 to 5724 counts (3.0 to 5.99 METS)

Strenuous activity: 5725 to 9498 counts (6.0 to 8.99 METS)

Very Strenuous activity: > 9498 counts (> 9 METS)

For our study, activity counts were summed for each day the participant wore the monitor (activity counts per day). This activity count value was then divided by the number of minutes worn for each day (activity counts per minute). Finally, the activity counts per minute for each day were averaged over number of the days worn (average activity counts per minute).

Actigraph activity count data was collected a week prior to the start of intervention (baseline) and at 12 weeks following the completion of their intervention. Actigraph activity data was set to record in one minute epochs over 7 consecutive days while the participants performed their habitual daily activities. An epoch is the time period in which activity data is presented providing a way to change the resolution or depth of detail in which you can view your data. One minute epochs are commonly used in investigating activity count data in adults.[80] Previous research has revealed that for adults, 3 to 5 days of monitoring is required to reliably estimate the measurement outcome variables typically used in accelerometry studies. [42,87,88] Therefore, we excluded participant data if they did not wear the accelerometer for at least 3 days.

We distributed the accelerometers to participants on a face to face basis to ensure participants were briefed about the care and use of the monitor. [83] The research staff verbally instructed and physically demonstrated to the participants the placement of the accelerometer; on the waist aligned with the midline of the right thigh. It makes little difference whether the monitor is worn on the right or left side but it is important to have a standard protocol suggesting that one side be used consistently.[50] Positioning on the waist, hip or low back are well suited for picking up accelerations that occur during normal ambulatory movement [59,83-85] and have been shown to yield the best prediction of energy expenditure.[85,86] We provided the participants with a 7 day activity journal asking them to record 1) the time the monitor was put on in the morning 2) the time the monitor was removed at night and 3) any time during the day that the monitor was removed for greater than a 30 minute period (i.e. to shower, swim, for MD appointments requiring X-rays or MRIs). For participants who had their first or last few treatment sessions during the baseline or follow-up testing, they did not wear the Actigraph during their intervention sessions. The participants were asked to keep the monitor on until they were ready to fall asleep as to avoid premature removal of the monitor. In previous work, it has been noted that participants often remove the monitor near the time of sleep but remain awake for minutes to hours (i.e. reading or watching television) before they actually fall asleep.[156] We considered 8 hours of wear time to signify a full day (if a participant wore the monitor for less than 8 hours that day was not included). The participants were given an information reminder front sheet for accelerometer use as well as a cell phone contact number of a research staff member who would be available 7 days per week to address questions and concerns.

4.2.3 Mobility Measure

4.2.3.1 Gait Speed

Gait speed was assessed as the time in seconds to complete a 4 meter walk at their usual gait speed. This was repeated twice and the average of these 2 walks was used for gait speed in meters per second. Previous work in older adults with mild to moderate mobility difficulties identified 0.05 m/sec as a small meaningful change in gait speed and 0.1 m/s as a substantial change. [173] A slower gait speed has been previously shown to correlate with reduced physical activity. [175] Identifying a clinically meaningful cut point for gait speed of 1.0m/sec, Cesari et al in 2005 found participants who walked <1.0 m/sec were at greater risk for lower extremity limitation, death, and hospitalization within one year.

4.2.4 Physical Function Measure

4.2.4.1 Physical Performance Test

The 7 item PPT test was used to assess multiple domains of physical function by asking participants to perform tasks meant to simulate activities of daily living (i.e. writing a sentence, turning 360 degrees, putting on and removing a jacket, walking 50ft). Scoring for each task is based on an ordinal scale 0 “unable to perform” to 4 “fastest or best performance”. The total 7-

item PPT score ranges from 0-28 with higher scores indicating better function. In a sample of 179 older adult subjects from various residences (i.e. community dwelling to nursing home) the 7- item PPT was found to be reliable (inter-rater Pearsons r=0.93; Cronbach's alpha = 0.79) and demonstrated concurrent and construct validity with other measures of function and health. [161] Scores on the PPT were found to be moderately to highly correlate with instrumental and basic activities of daily living scales, Tinetti gait score, self reported health status, cognition, mental health and age. [161] We set a change of 2 points on the PPT to signify improvement and scores of less than 2 points to signify no change or decline. We were unable to find previous literature to support meaningful change scores of the PPT.

4.2.5 Statistical Analysis

All statistical analyses were performed using version 15.0 SPSS software (SPSS Inc. Chicago IL). We had a single group before and after intervention design where our participants, who were expected to undergo a change in mobility, were measured at two points in time. Descriptive statistics (means, standard deviations and ranges) were reported for all variables of interest at baseline and 12 weeks. We used paired-t tests to look at intra-individual change over time in activity CPM, mobility (gait speed), and function (PPT) measures. Pearson correlation coefficients were then used to investigate the relation of mobility and function with activity CPM at both baseline and post-intervention time points.

Two distribution based (effect size and standard error of the measurement) approaches and one anchor based (means comparison using mobility and function as anchors) approach was used to determine magnitudes of meaningful change in Actigraph CPM. Distribution based interpretation of change relies on psychometric properties of a measure in a population to estimate effect size or standard error of measurement. The distribution based approach looks at statistical significance of change score. **Effect size** provides direct information on the magnitude of change in a measure considering the measures variation. [176] For our study, the effect size based estimate for a small change was computed as 0.2 multiplied by the standard deviation of activity CPM at baseline and for a substantial change was computed as 0.5 multiplied by the standard deviation of activity CPM at baseline. Small meaningful change was based on literature recommendations for minimally significant change as an effect size of 0.2 and substantial change as an effect size of 0.5. [176,177] **Standard error of the measurement** (SEM) is assessed by taking the standard deviation of the measure at baseline and multiplying it by the square root of 1 minus the test-retest reliability. SEM is considered to be a fixed characteristic of any measure regardless of the sample of participants under investigation so in repeated samples drawn from the same population, the SEM should be similar.[174] SEM may be more appropriate for interpreting intra-individual change compared to effect size because effect size is sample dependent since it only measures standard deviation. [174] There is no consensus about how many SEMs a measurement score must change to be considered meaningful (i.e. 1 vs. 1.96 [178] vs. 2.77[179]) and statistically meaningful change does not equate to clinical meaningfulness.[174]

Anchor Based interpretation of change is where a clinical standard for comparison based on other measures (an expected change caused by time, therapy, known disease diagnosis or life events) is used as an external anchor to determine corresponding magnitude of change in the measure of interest.[174] The external anchor in this study was change in mobility and function due to the intervention and the measure of interest was Actigraph CPM. We based our design on the direction of change in the mobility and physical function since gait speed, physical performance /function and physical activity are typically moderately to highly correlated. Finally we investigated mean differences in activity CPM at baseline for those who improved, worsened or stayed the same in mobility and function over the 12 weeks of exercise intervention.

4.3 RESULTS

We had complete baseline and 12 week post intervention data on 86% (43/50) of our participants [3 participants completed baseline testing but did not return for intervention due to health, scheduling, and personal reasons/ 3 participants completed a portion of the intervention but dropped out due to health reasons (hospitalization, health decline, hip fracture) and with 1 participant the accelerometry data failed at post test]. Demographics did not differ for the 7 participants with incomplete Actigraph data compared to the 43 with complete data. Mean baseline, 12 week and change values for activity CPM, mobility (gait speed) and function (PPT test scores) are presented in Table 15. Comparing baseline to 12 week post intervention time points via paired t-tests, activity CPM were not significantly different however mobility and physical performance did undergo a significant improvement with intervention. (See Table 15 for p values) Also, gait speed and PPT scores were moderately correlated to Actigraph CPM at baseline (Pearson $r = 0.33$; $p = 0.029$ and $r = 0.55$; $p<0.001$ respectively) and 12 week post intervention (Pearson $r = 0.47$; $p =0.002$ and $r = 0.43$; $p = 0.002$ respectively).

Table 15 Mean baseline and 12 week physical activity, mobility, and function measures

Mean (SD)	Baseline	12 week	Change score	P value
Actigraph CPM	135.5 (63.9)	131.7 (60.9)	-3.8	0.455
Gait speed m/s	0.90 (0.14)	1.03 (0.18)	0.13	< 0.001
PPT	20.7 (2.5)	22.3 (2.6)	1.6	0.001

A small effect size for Actigraph CPM was calculated to be 12.78 whereas a substantial effect size was calculated to be 31.95 activity CPM. To calculate standard error of the measure for activity CPM, a test re-test reliability of 0.80 was used. Previous literature reports test-retest values for the Actigraph accelerometer ranging between 0.5 to 0.99. [90,93-95] We chose 0.80 based on a study by Welk in 2004 in adults where Actigraph counts per minute were recorded during 3 separate bouts of treadmill walking. Unfortunately, no studies to date have investigated the test-retest reliability of the Actigraph accelerometer during free living conditions in older adults. Therefore, the standard error of the measurement for activity CPM was 28.6. Considering the substantial effect size (31.95) and standard error of the measurement (28.6) for the Actigraph CPM, it was assumed a change of 30 CPM was considered significant outside of spurious change / error.

Further analysis of baseline Actigraph CPM values revealed that the participants who improved in gait speed were significantly more active at baseline compared to those who did not improve or declined in gait speed ($t = -2.6$; $p = 0.01$). Participants who improved in PPT scores were also more active at baseline as evidenced by higher Actigraph CPM compared to those who did not improve or worsened in PPT scores but the values did not reach statistical significance (t

= -1.5; p=0.13). Refer to Table 16 for Actigraph CPM values in each of the groups described above. Also, if you consider the substantial effect size and standard error of the measure for Actigraph CPM found in this study, 30 CPM would be considered a substantial change outside of error. Actigraph CPM at baseline differed 56.0 CPM and 29.7 CPM for those who improved versus those who did not improve or worsened in gait speed and PPT scores respectively. These differences in Actigraph CPM at baseline were present even though gait speed did not differ at baseline in those who at 12 weeks improved versus those who did not improve or worsened in mobility (t = 0.42; p = 0.67) and function (t =0 .29; p = 0.77). PPT scores were also not different at baseline in those who at 12 weeks improved versus those who did not improve or worsened in mobility (t = -.86 ; p = 0.39) and function (t = 1.8; p = 0.07). Specifically, as shown in Tables 17 and 18, there seems to be a dose response relation in Actigraph CPM when investigating future change in gait speed and physical function. Those who worsened in gait speed and physical function were less active at baseline than those who remained stable in gait speed and function, followed by those who improved in gait speed and function.

Table 16 Mean physical activity counts per minute versus mobility and function change over time

	MOBILITY		**FUNCTION**	
Activity CPM	No change or worse (< 0.05m/s) N=10	Improvement (≥ 0.05m/sec) N=33	No change or worse (<2) N=19	Improvement (≥ 2) N=24
Baseline	92.5 (54)	148.5 (61.5)	118.9 (58.6)	148.6 (66.0)
12 week	90.7 (53.6)	144.1 (58.1)	125.6 (59.1)	136.5 (63.1)
Change	-1.9	-4.3	6.7 (30.1)	-12.1 (32.7)

Table 17 Mean physical activity versus gait speed change groups over time

Actigraph CPM Mean (SD)	Worse (< - 0.05 m/s) N=4	Stable (≥ -0.05 to < 0.05) N=6	Mild Improvement (>0.05 to < 0.10) N=5	Moderate Improvement (≥1.0) N= 28
Baseline	**63.5 (42)**	**111.0 (51)**	**130.2 (43)**	**148.5 (66)**
12 week	74.6 (48)	101.4 (59)	136.5 (30)	145.5 (62)
Change	11.1	-10.5	6.3	-6.3

Table 18 Mean physical activity versus physical function change groups over time

Actigraph CPM Mean (SD)	Worse (≤ -2) N = 6	Stable (≥ -1 to ≤ 1) N=13	Improved (≥ 2) N=24
Baseline	**107.8 (81.0)**	**124.0 (48.2)**	**148.6 (66)**
12 week	122.2 (68)	127.2 (58)	136.5 (63.1)
Change	14.4	3.2	-12.1

4.4 DISCUSSION

Meaningful change values of Actigraph CPM were established in this study of community dwelling older adults with mobility disability. A substantial meaningful change was found to be 31.95 CPM with a standard error of the measure of 28.6 CPM. As expected, Actigraph CPM were correlated with both mobility and physical function measures at baseline and post intervention time periods yet activity CPM did not change over the course of the intervention as mobility and physical function changed. However, the participants who were able to clinically meaningfully improve their gait speed and physical function with exercise intervention were more active at baseline than those who were unable to improve or even worsened in gait speed and/ or physical function with intervention. Several other studies have found that regular exercise training sessions did not lead to an increase in physical activity levels in older adults. {Goran; 1992; Meijer 1999} One such study was performed by Meijer et al in 1999 who found older adults who underwent an exercise program 2 times a week for 12 weeks did not show a change in accelerometry based physical activity from baseline to after intervention. However, the exercise program did lead to changes in physical fitness (heart rate response, increased oxygen consumption) [180]

There is the possibility that physical activity measured by Actigraph CPM may be an early indicator of who is able to respond and improve mobility and physical function due to the exercise intervention. Perhaps those who are more physically active at baseline are overall more capable of performing physical activity at home and in the community. Therefore they may be better able to comply and carry over exercise recommendations given during intervention. Those who are less physically active at baseline may not have the capacity to carry over exercise recommendations at home or in the community and may need the supportive environment and supervision of the research space in order to properly implement the strategies they have learned. Another possibility could be that mobility and physical function changes occur prior to changes in habitual physical activity levels. Maybe someone is first able to walk faster then they build more confidence and finally they change their physical activity routines at home and in the community.

Our study had several strengths. This study was the first to establish significant effect size and SEM for Actigraph activity CPM in community dwelling older adults with mobility disability. Most of the previous studies in Actigraph accelerometry have been performed in younger to middle aged adults. Our participants' activity was measured over the period of a week in free living conditions versus a laboratory environment. Test –retest reliability improves with increased days of wear.[83, 84] Also, we had performance based measures of both mobility and physical function to compare our activity data. Finally, in our 43 participants who completed the study, only one accelerometer failed and led to missing data. No accelerometers were lost or broken during the 7 days of wear at baseline or post-testing.

There were several limitations associated with our design. With no change detected between the Actigraph CPM, it is unclear whether the measure was unable to detect a change or whether the intervention did not lead to a change in physical activity. The goal of the exercise intervention was to improve mobility. We expected if mobility improves, that physical activity would increase but that is not necessarily the case. Just because a participant can do more regarding mobility doesn't mean they will take the additional time or effort to increase physical activity. Also, our study design does not allow for the assessment of the Actigraph CPM on participants whose status is stable,[170] we were expecting a change in mobility and function thanks to the intervention .

In future work there is a need to establish test-retest reliability of Actigraph CPM in community dwelling older adults in free living situations over a week. Test re-test reliability of the Actigraph has mostly been performed in laboratory settings during treadmill or overground walking, simulated activities of daily living, or using mechanical shaker tables. Also, most test-re-test reliability of the Actigraph CPM has been performed in healthy young to middle aged adults. Finally, it is important to assess Actigraph CPM in addition to self reported activity, mobility and physical function in older adult participants whose status is expected to be stable (i.e. no intervention to change mobility or performance) over a period of time such as 6 months or a year.

4.5 CONCLUSION

We found a substantial meaningful change value of 31.95 CPM with a standard error of the measure of 28.6 CPM for the Actigraph accelerometer in community dwelling older adults with mobility disability. In these adults, Actigraph CPM were correlated with mobility and physical function at baseline and following intervention. Surprisingly, activity did not undergo a significant improvement with the intervention even though mobility and physical function improved. However, those participants who were able to improve in mobility and physical function with intervention were more active at baseline than those who did not improve or worsened.

5 SIGNIFICANCE AND DIRECTION OF FUTURE RESEARCH

The compilation of these three projects has helped to establish meaningful Actigraph acclerometry values for use in community dwelling older adults. The majority of work in accelerometry to date has been performed in laboratory conditions with young to middle aged healthy adults. There is a growing need to accurately and precisely assess physical activity in older adults who are at risk for or overwhelmed by chronic health conditions associated with physical inactivity. With chronic health conditions and physical inactivity comes problems with independent mobility, functioning and performance in everyday tasks. Defining meaningful values for the Actigraph accelerometer to measure physical activity helps to advance the assessment of physical activity in older adults both in research and clinical settings.

We were able to establish inter-rater reliability for the multiple data outputs available from the Actigraph accelerometer. However we discovered activity counts per minute was the data output with excellent test-retest reliability and known groups validity against measures of mobility, function, and self-reported activity. This is also the output that requires the least amount of data processing and is suggested by the manufacturer as the output with the least amount of error. We were able to add further meaning to activity counts per minute by establishing meaningful cut-points for mobility and function problems as well as meaningful change scores. In older adults identified to have mobility disability, those accumulating less than 150 CPM averaged over a week's wear were more likely to have mobility and function problems. Also, a change of 30 CPM averaged over a week's wear indicates a substantial meaningful change in physical activity outside the realm of spurious change.

In our small sample of community dwelling older adults, we did not find expected correlations of energy expenditure (oxygen rate or METs) with Actigraph counts as has been found in younger adults. Although, older adults did have higher energy expenditure and more activity counts during usual versus slow walking conditions confirming that both measures were able to distinguish a difference in activity intensity. We would recommend caution using equations which have been established in younger adults to predict energy expenditure of older adults from accelerometry data. A need exists to develop energy expenditure prediction equations for a larger sample of various older adults populations [i.e. those who are healthy and community dwelling, those living in supportive settings (assisted living, nursing home), those with chronic conditions] because their behavior may vary from that of younger adults due to changes in gait patterns, body compositions, and physiological processing that occur with aging. Investigations should be carried out in older adults using triaxial accelerometers or multiple accelerometer placements to assess if these techniques would improve the prediction of energy expenditure. Triaxial accelerometers are able to detect medial-lateral and anterior –posterior accelerations which may contribute to increased energy expenditure in older adults. Since energy expenditure and accelerometry data has been highly correlated in younger adults, the increased cost and burden of data analysis for triaxial accelerometer use is most likely not necessary in younger adults.

Also, there is a poverty of research establishing accelerometry activity cut points for clinically meaningful end points (i.e. balance dysfunction, ADL difficulties, future health decline). Furthermore, a standard calibration equation for various makes and models of accelerometers needs to be established to assess physical inactivity, the purposeful use of time to engage in activities which are sedentary in nature (TV watching, reading, computer work).[50] Finally, as technology continues to advance accelerometers should improve in the ability to detect energy expenditure of various free living activities while remaining small, unobtrusive, with sufficient data storage capabilities. This may be accomplished in the future by combining digital computer based logging of activity, heart rate monitoring, and/or global positioning technology with accelerometry. The advances in technology would have to be achieved while keeping the cost of the units down in order to make them feasible in the clinic or research based settings.

Considering all three projects involved in this dissertation, all Actigraph accelerometers were recovered. In total the accelerometers were sent out approximately 100 different times to capture habitual daily activities in participants and all were returned and none were broken. This supports that accelerometers despite their expense could be issued to participants/ patients in both research and clinical settings.

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