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REPLACING SEDENTARY BEHAVIOR WITH A LIGHT INTENSITY PHYSICAL ACTIVITY IN THE HOMES OF OLDER ADULTS

by

Nicholas Louis Lerma

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ABSTRACT

REPLACING SEDENTARY BEHAVIOR WITH LIGHT-INTENSITY PHYSICAL ACTIVITY IN THE HOMES OF OLDER ADULTS

by

Nicholas Louis Lerma

The University of Wisconsin-Milwaukee, 2018
Under the Supervision of Professor Scott J. Strath, Ph.D.

Aging is positively correlated with time spent in sedentary behavior (SB), which has been found to be linked to premature mortality, cardiovascular disease risk, and functional limitations. Moderate-to-vigorous-intensity physical activity (MVPA) is a potent stimulus for preventing and improving functional limitations in older adults, but less than 17% of the older adult population meets the recommended PA guidelines. While increased time spent in SB is detrimental to health in all, the impact among those that are physically inactive appear to be most pronounced. Recent evidence suggests increasing light-intensity physical activity (LPA) in these populations may provide health benefits and could be a more practical approach for older adults.

The purpose of this dissertation project is to identify safe, effective, and practical evidence-based approaches to reduce SB to maintain or improve physical function in late life. Therefore, the aims of this dissertation project are three fold: 1) to identify the impact of replacing time spent in SB with physical activity on measures of physical function in community-dwelling older adults, 2) identify the feasibility of using a seated portable elliptical device (SED) in the homes of older adults, and 3) determine the effectiveness of using a SED to replace time spent in SB with a LPA and explore the impact on measures of physical function in older adults.

An isotemporal substitution regression model identified that replacing as little as 30 minutes of SB with LPA led to significant improvements in walking speed. Meanwhile, replacing up to 60 minutes of SB with LPA led to larger magnitudes of improvement which approached clinical relevance. Further, supplementing LPA with MVPA progressively increased the improvements in a battery of functional assessments. Interventions to reduce SB have come with difficulty and methods to purposefully replace SB with PA should be developed to test the validity of the findings from these novel statistical models.

A seated elliptical pedaling device (SED) was used to purposefully target reducing SB and replacing with LPA, while allowing participants to maintain the enjoyment of their typically passive activity in their home. A one week trial study identified that there was no difference in the ability of older adults to accumulate between 15 to 60 minutes of pedaling per day. Further, there was high acceptability among all participants that were randomly assigned to either 15, 30, 45, or 60 minutes per day pedaling groups. This led to the development of an 8-week pilot randomized controlled trial using the SED. In this trial, the intervention was effective at replacing SB with LPA as identified by a group by time interaction effect. Specifically, the elliptical group (EG) experienced a significant 7.3% ($p = 0.003$) reduction in daily SB and 7.1% ($p = 0.002$) increase in LPA between baseline and follow-up testing compared to no significant difference in the control group (CG). Participants suggested improvements in function, but small effect sizes and sample sizes did not produce significant improvements in measures of physical function.

Introducing a SED during passive activities in the home is a feasible and effective approach at reducing daily SB in older adults. While some of the functional tests did exhibit ceiling effects among those that were high functioning at baseline, subjective responses from

individuals of lower functioning suggest the potential for impacting the QOL of those that have difficulty performing ambulatory activities. Future investigations using the SED should be directed toward longer intervention periods, with larger sample sizes, and among individuals of various levels of functional ability and life circumstances.

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LIST OF ABBREVIATIONS

β : beta-coefficient
e^{β} : base-e log back transformation
30STS: 30-second sit-to-stand test
400W: 400-meter walk time
5xSTS: Five-repetition sit-to-stand test
ABC: Health, Aging, and Body Composition Study
ADL: Activities of daily living
BMI: Body mass index
BRFSS: Behavioral Risk Factor Surveillance System
CI: Confidence intervals
CMD: Clinically meaningful difference
CPM: counts per minute
CRF: Cardiorespiratory fitness
CS-PFP-10: Continuous Scale of Physical Functional Performance test
CVD: Cardiovascular disease
d: Day
GPS: Global positioning system
HAPA: Health Action Process Approach
HCBS: Home and community-based services
hr: Hour
hz: hertz
iADL: Instrumental activities of daily living
ICC: Intra-class correlation coefficient
ICF: International Classification of Functioning, Disability, and Health
IRT: Item response theory
IPAQ: International Physical Activity Questionnaire
ITT: Intention to treat
kcal: Kilocalories
kg: Kilogram
kgFFM: Kilograms of fat free mass
LLFDI: Late-Life Function and Disability Instrument
LPA: Light-intensity physical activity
LTSS: Long-term supports and services
MAQ: Modifiable Activity Questionnaire
$m \cdot s^{-1}$: Meters per second
MET: Metabolic Equivalent of Task
MetS: Metabolic syndrome
MCID: Minimally clinically important different
MIC: Minimally important change
min: Minutes
$min \cdot d^{-1}$: Minutes per day
MPA: Moderate-intensity physical activity
MVPA: Moderate-to-vigorous-intensity physical activity
n: sample size

NHANES: National Health and Nutrition Examination Survey
NHIS: National Health Information Survey
p: probability value
PA: Physical activity
PAEE: Physical activity-related energy expenditure
PAR: Physical Activity Recall
PDPAR: Previous Day Physical Activity Recall
PP: Per Protocol
PWMAQ: Previous Week Modifiable Activity Questionnaire
r: Correlation coefficient
R^2: Coefficient of determination
RCT: Randomized control trial
RPAQ: Recent Physical Activity Questionnaire
s: Second(s)
SB: Sedentary behavior
SD: Standard deviation
SE: Standard Error of the estimate
SED: Seated elliptical pedaling device
SF-36: RAND 36-Item Health Survey
SPPB: Short physical performance battery
TUG: Timed up-and-go
UGS: Usual gait speed
VPA: Vigorous-intensity physical activity
wk: Week
WHAS: Women's Health and Aging Study
WHO: World Health Organization

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CHAPTER I: INTRODUCTION

Background and Statement of Problem

Aging and Functional Health

Twentieth century advancements in medical technology have allowed individuals to escape mortality and reach older age at unprecedented rates. Once reaching the age of 65, the average life expectancy is an additional 19.7 years (US Department of Health and Human Services, 2014) and often these years are plagued by the onset and accumulation of several chronic diseases, resulting in a triage-like management of geriatric care. This type of healthcare management often fails to recognize the underlying age-related changes that result in a population that is suffering from physiological decline and loss of functional health. One of the hallmark consequences of aging is a continual loss in muscle mass which contributes to a 1-1.5% annual decline in muscle strength with reductions in physical function and mobility (Frontera et al., 2000; Doherty et al, 2003; Rolland et al., 2008; Buchman et al., 2007) and increased risk for falls, disability, frailty, hospitalization, institutionalization, and mortality (Xue et al., 2011).

Economic Impact of Functional Health

In 2012, approximately one in three older adults experienced some sort of disability that increasingly resulted in the use of supportive services as age increased (US Department of Health and Human Services, 2014). Age-related neuromuscular changes have led to over $20 billion in direct health care costs, exceeding the costs of osteoporosis related-hospitalizations by $2 billion (Jansen et al., 2004). While public resources like Medicare, Medicaid, and Social Security have been developed to provide medical and financial support systems for older adults with accumulating medical expenses, the outdated infrastructure of these services is being stressed as

Medicare and Medicaid take up nearly one-fourth of the 2014 Federal Budget and Social Security only remaining solvent until 2037. Further, the exceedingly high costs of long-term supports and services (LTSS) made up over one-third of Medicaid spending in 2013 (Kaiser Family Foundation, 2015) with age-associated functional costs expected to drastically increase as the 85+ year old population doubles by 2030 and triples by 2040 compounded with healthcare costs that are outpacing inflation (Clark and Manini, 2010; US Department of Health and Human Services, 2015). While functional impairments have a significant impact on the nation's economy, the social and economic effects at the personal level can be devastating.

Gaps in coverage between Medicare, Medicaid, and availability of long-term care insurance result in excessive out-of-pocket spending that can detrimentally impact the financial well-being of families. Because Medicare is not authorized to provide LTSS, Medicaid is the default public resource to provide LTSS with a limited cap on personal assets. This gap in LTSS coverage often results in the liquidation of assets and induced poverty. Specifically, 70 percent of private pay customers who enter a skilled nursing facility are impoverished within three months and 90 percent reach poverty within a year (Moody & Sasser, 2011).

"Aging in Place" is an initiative that has been influenced by the needs and preferences of older adults combined with the forecasted demands in long-term care and the exceedingly high costs of skilled-nursing facilities. In 2016, the median annual cost of a semi-private skilled nursing facility in Wisconsin was approximately $93,805 whereas adult daycare may cost less than $18,000 per year ("Compare long term care costs," 2016). Also, 87 percent of polled 65+ year olds stated that they would prefer to stay in their home or communities while aging ("Survey, what makes a community livable," 2014) and the 1999 Olmstead US Supreme Court decision ruled that the unjustified institutionalization of many older adults violated the

Americans with Disabilities Act. These factors have contributed to the development and implementation of policies that favor home and community-based services (HCBS) for the elderly to “Age in Place”. Although the share of Medicaid HCBS expenditures has tripled since 1995, bias toward institutionalization remains with long-term care costs exceeding $214 billion in 2014 with many communities lacking adequate resources and infrastructure to promote “Aging in Place”. While age-related changes in functional health are inevitable, novel research is indicating that the trajectories toward a disability threshold can be augmented by reducing sedentary behavior (SB) and increasing PA. This will be discussed in the following section.

Sedentary Behavior and Physical Activity with Function

Key predictors of nursing home placement include underlying cognitive and/or functional impairment with a lack of support for performing activities of daily living (ADL) (Luppa et al., 2009). There is strong evidence that physical activity (PA) is effective in maintaining cognitive and physical functioning in older age (Nelson et al., 2007), which may influence life-space mobility and the ability to perform ADLs independently (Pahor et al., 2014, Tsai et al, 2016)[1]. However, one of the most consistent findings in epidemiology is the continual decline of PA with aging (Sun, Norman, & While, 2013). Specifically, older adults are a sub-population that has been identified as the least physically active, in terms of presenting an age demographic with the largest proportion not in fulfillment of the PA guidelines and, on average, accumulating the least amount of time spent in moderate-to-vigorous intensity PA on a daily basis (Matthews et al., 2008).

Further, population-based observations have identified that time spent in SB increases with age resulting in older adults spending approximately 60-80% of their waking hours in SB

(Matthews et al., 2008; Healy et al., 2011). Much of this time is spent sitting among older adults is linked to specific home-based leisure activities including TV viewing and other recreational screen-based activities (Owen et al, 2011). TV viewing time and SB are linked to several non-communicable diseases, loss of physical function, and premature mortality in older adults (Hamilton, Hamilton, & Zderic, 2007; Healy et al., 2008; Katzmarzyk, Church, Craig, & Bouchard, 2009; Kim et al., 2013; Matthews et al., 2012; Owen et al., 2011; Warren et al., 2010). This detrimental relationship between SB with health and function remains even after accounting for PA participation (Healy et al., 2008; Owen et al., 2011; Gennuso et al., 2013, Seguin et al., 2012). For example, Seguin and colleagues (2012) identified that in every category of PA the declines in self-reported physical function were greatest in women reporting higher amounts of SB, while those least physically active and accumulating the most SB time experienced the most dramatic decreases in physical function.

The independent influences between SB and PA with physical function are suggestive to distinct physiological mechanisms that may need to be targeted individually and concurrently. Through the principle of specificity, the progressive overload of PA can include, but is not limited to, beneficial anabolic responses neuromuscular systems (Baechle and Earle, 2000, Pearson, Faigenbaum, Conley, and Kraemer, 2000) which is in contrast to the catabolic responses of neuromuscular disuse during sedentary behavior leading to neuromuscular atrophy (Hamilton, Hamilton, and Zderic, 2007). Further, a theoretical cyclical relationship is suggested between SB, PA, and physical function in the elderly. This relationship can be described as an age-related progressive loss of muscle mass, functioning, and vitality that may concurrently contribute to a decline in PA participation and increased SB adoption (time in one behavior directly affects time spent in another). These trajectories in PA and SB may dually exacerbate the age-related decline in muscle strength and the physical ability to participate in healthy levels of PA and avoidance of SB. The inter-relationship between these variables can introduce older adults to a vicious cycle in aging that leads to accelerated functional decline and increased susceptibility for loss of independence (Tsai et al, 2016). Therefore, population-based monitoring of PA and SB may serve as easily identifiable risk factors for subsequent premature disability. Secondly, these modifiable risk factors may become apparent as a point of entry to intervene for the purpose of counteracting these trajectories for the maintenance in the functional health of older adults in late life.

Insights into the relationship between SB, PA, and physical function in the elderly have not been consistent. This may be due to the current nature of the evidence, highly relying on observational studies that identify the strength of relationships between SB, PA, and functional health while using various measurement instruments and analytical methods. In particular, while self-report methods are inexpensive to administer and provide greater reach in epidemiological studies, they possess limitations in reliability and validity compared to objective or direct measures of PA, SB, and functional health (Matthews et al 2012, Prince et al 2008, and Kempen et al 1996). Additionally, many SB and PA self-report questionnaires fail to ask about light-intensity physical activity (LPA), which has recently been suggested as an important variable to functional health benefits in the elderly (Buman et al 2010, Pahor et al 2012, Tsai et al 2016). To derive more accurate relationships between SB and PA with functional health, objective measurement techniques that measure the entire continuum of PA must be included in studies. Advances in technology have allowed for the development of affordable and wearable devices to measure SB and PA through accelerometry and novel analytical techniques.

Intervening on Sedentary Behavior

Attempts to intervene on SB have not come without difficulty, which is likely due to the imbedded behavioral nature of several SB activities. A recent meta-analysis examining the effectiveness of PA, lifestyle, and SB interventions at reducing daily SB identified an average reduction of 22 min/day or 4% of SB time (Martin et al. 2015). Further, the most impact was made by interventions purposefully targeting SB and presented no evidence that the carryover of isolated PA interventions is effective at reducing SB time. Therefore, in order to decrease SB and increase PA these behaviors should be targeted concurrently with the focus of displacing time in SB with PA utilizing the implementation of behavioral strategies. Further, Manini and colleagues (2012) suggest that SB interventions should be tailored to specific populations and focus on important health outcomes. Future interventions should be effective, practical, acceptable, and affordable for an older adult population at risk of spending a majority of their days spent in SB and focus on functional health and quality of life as outcomes.

Altering the physical environment surrounding the underlying behaviors, such as introducing active workstations, have shown some effectiveness in reducing SB time in younger adults, but may not be suitable for in-home use of older adults (Owen et al. 2011). Several of these devices are cumbersome, uncomfortable, and expensive. A seated portable elliptical device (Stamina, InMotion) has recently been introduced as a potential method to interrupt SB with a LPA in young and old adults. Previous work has identified this device's ability to increase energy expenditure out of the SB range and presented high interest among participants (Carr et al., 2014; Rovniak et al., 2014). While these studies focused on younger to middle aged working class individuals, previous work in our laboratory identified similar findings among older adults aged 60+ years old (Lerma et al., 2017). In particular, pedaling at a self-selected pace in three different contexts (television, reading, typing) presented energy expenditure increases equivalent to walking 2,000 steps/hr with high acceptability and comfort. These findings are important because the introduction of the portable elliptical device allows for a comfortable and easy to perform LPA to displace time that would otherwise be spent in a SB without interrupting the underlying task being performed.

Future work is needed to determine the frequency, intensity, and duration of SB time displacement by PA to improve functional measures and health in older adults and if the lab-based efficacy studies will translate into the real-world. In particular, while decades of research has identified the utility of incorporating at least 30 minutes of MVPA per day into an older adults routine can have a strong influence on health there is not much information regarding the influence of lower levels of activity on function. Further, it is unknown how often, how long, and how well older adults will use this device during SB activities in the home. Also, the determination of a drop off in adherence with the device may identify the necessity and timing for introducing behavioral intervention strategies. These very important questions must be answered before implementing such a device in a randomized controlled trial to investigate potential alterations in longitudinal health and functional-related variables.

Summary of the Introduction

Progressive increases in SB and decreases in PA that occur with aging may lead to an introduction to a vicious cycle of accelerated and premature loss in functional status among older adults. More information is necessary to determine the independent relationships that may be present between these variables with the use of objective measurements and appropriate analytical techniques. The inability of PA interventions to provide a carryover effect to reduce SB time, in addition to the difficulty of interrupting or breaking up SB with a PA stimulus, calls for more practical approaches that specifically target SB. Practical strategies that alter the physical environment to promote PA and allow for the underlying behavior to carry on uninterrupted could lead to better adoption and adherence. Interventions that are designed to concurrently reduce SB by incorporating continuous movement in large muscle groups may provide the dual effects of interrupting the muscle wasting environment and provide a platform to progressively build towards greater workloads and physical capabilities. Laboratory-based efficacy studies investigating a portable elliptical device has shown high acceptability with the ability to exceed a low-energy state while seated. The adoptability and effectiveness of altering functional-related outcomes using this portable elliptical device are unknown.

Therefore, the following three studies are designed to assess the potential impact of replacing 30 to 60 minutes of SB with PA on various measures of physical function, determine the feasibility and acceptability of replacing up to 60 minutes of SB with LPA in the homes of older adults, and determine the effectiveness of using a seated elliptical pedaling device (SED) to reduce SB in the homes of older adults.

Isotemporal Substitution of Sedentary Behavior and Physical Activity on Function

Statement of Purpose

To investigate the relationship of displacing objectively measured PA and sedentary behavior SB time on performance measures of physical function in a sample of community dwelling older adults.

Specific Aims

To determine the relationship of replacing SB with LPA and/or MVPA on measures of functional performance in community dwelling older adults.

Hypothesis

It is hypothesized that replacing 30 minutes of SB with LPA and/or MVPA is linked to significant improvements in functional performance in community dwelling older adults.

In-home use of a portable elliptical device during seated activities in older adults

Statement of Purpose

To assess the acceptability and feasibility of using a seated elliptical device to interrupt and/or replace SB with a LPA in the homes of older adults.

Specific Aims

To measure if group differences exist in accumulating 15, 30, 45, or 60 minutes of daily light-intensity pedaling using a seated elliptical for at least three days in a one week trial in the homes of older adults.

Hypothesis:

It is hypothesized that there will be no difference in the proportion of individuals from each group meeting the three times per week duration goals for SED in the homes of older adult.

Replacing Sedentary Behavior with Light Intensity Physical Activity in the Homes of Older Adults: Pilot Randomized Controlled Trial

Statement of Purpose

To determine the effectiveness of a progressive home-based intervention using a SED to reduce SB, increase LPA, and improve physical function in older adults

Specific of Aims

This study had two specific aims: 1) to assess the effectiveness of progressively increasing SED pedaling time to reduce SB in the homes of older adults over eight weeks and 2) measure the impact of replacing SB with a seated LPA on functional outcomes in older adults.

Hypothesis

It was hypothesized that older adults in an intervention elliptical group (EG) using the SED will experience reduced SB compared to a control group (CG) and reductions in SB time will lead to improved measures of physical function.

CHAPTER II: LITERATURE REVIEW

Introduction

The US is currently experiencing an unprecedented era of aging due to the compounded effects of increased life expectancy during the 20th century and the arrival of a population wave notably identified as the *Baby Boomers.* In 25 years, one in five Americans will be 65+ years old and during this same period the 85+ year old population will be the fastest growing demographic increasing two-fold by 2040 and tripling by 2050 (Administration on Aging, 2016). Modern medical technology has facilitated increased rates of older adults successfully reaching advanced age, leading to a growing population susceptible to the accumulation of chronic-degenerative pathologies and compromised functionality.

With advanced age there is an increased presence for physiological decline, functional limitations, and loss of independence. With a primary focus on the effective treatment of immediately life-threatening comorbidities the progressive and generalized loss of muscle mass inherent with aging, or sarcopenia, remains (Rosenberg, 1989). Elderly people with sarcopenia experience triple the risk of developing frailty, impaired mobility, and disability (Fried et al., 2001, Frisoli et al., 2011). An expanding older adult population and no pharmaceutical-derived magic pill for omnibus age-related physiological decline has created a public health crisis as the increased prevalence and societal impact of functional limitations exacerbate an unprepared long-term care system. Specifically, sarcopenia-related medical costs in the United States exceed $20 billion per year (Janssen et al., 2004) and are increasingly putting a strain on public health care systems for the elderly with LTSS for older adults accounting for 28 percent of all Medicaid expenditures, or $123 billion (Kaiser Family Foundation, 2015).

Age-related patterns of PA and SB have been linked to the presence of functional limitations in older adults. Specifically, population-based studies have consistently identified that trajectories in the time spent in SB increases with age, while time spent in PA decreases (Jefferis et al., 2015). Further, time spent in PA and SB have been identified as prominent, modifiable risk factors for functional limitations in those reaching old age (Elsawy, 2010). While these progressive age-related changes are relatively unavoidable, skeletal muscle disuse through a lack of PA and increased SB appears to compound the risk of muscle function loss and mobility impairment (Tikkanen et al., 2012).

When analyzing these demographic characteristic, and its potential effect on functional outcomes, it is important to consider time spent in PA and SB directly affect one another with finite amount of time in the day. By intervening on SB and holding waking hours constant, any reductions of time spent in SB will be displaced by spending time in LPA, MVPA, or some combination of the two. Likewise, interventions focused on increasing MVPA time will then translate to reduced time spent in SB, LPA, or a combination of the two. However, there is no evidence that interventions focusing solely on MVPA will lead to reductions in SB time. A recent systematic review and meta-analysis of PA, SB, and PA+SB interventions identified that clinically relevant reductions in SB time were only present in interventions with a focus on reducing SB (Prince et al., 2014). Considering the negative effects of SB while controlling for MVPA, this information is vital to developing an effective functional health intervention in older adults. Therefore, the time spent in MVPA is likely to displace time spent in LPA while the independent, negative effects of SB may remain relatively constant.

There is mounting support that LPA may serve as a preventative measure and indicator of health, function, and mortality risk in advanced age (Buman et al., 2010). For example, leisurely walking provides contributions toward total daily energy expenditure and may consist of activities that are particularly important to older adults. With LPA serving as a pre-requisite for higher intensity activities, LPA may be an important stimulus for older adults and performing LPA may influence the ability to later perform higher intensities. Therefore, interventions designed with a purpose of impacting clinically relevant functional outcomes may have to purposefully target the displacement of SBs with opportunities of LPA or MVPA.

Currently, there is no universal agreement on the frequency, intensity, and type of PA necessary to promote functional maintenance and improvement in older adults. Further investigation on the effects of the entire PA continuum on functional health in older adults is warranted. Therefore, the purpose of this literature review is to investigate the impact of SB, LPA, and MVPA on the functional performance of older adults. The following chapters will highlight the aging US demographic, followed by theory on the functional reserve capacity of individuals as they age, and how trajectories in functional capacity toward a disability threshold may be altered by PA and SB habits.

Aging of America

Aging Trends

The 20th century will be remembered for population growth and the 21st century for an aging population. In the past century, the US experienced a 60 percent increase in life expectancy and more than a three-fold increased proportion of older adults (65+ years) in the US population. Specifically, the life expectancy in 1900 was 49.2 years and only 4.1 percent of Americans were 65+ years compared to 78.8 years and 14.9 percent in 2015 (Administration on Aging, 2016; Arias, Heron, & Xu, 2016). The absolute number of older adults aged 65+ years had increased more than 15-fold from 3.1 million to 47.8 million between 1900 and 2015, respectively (Administration on Aging, 2016).

While the aging American population may be perceived as normal in our lives, it is a relatively new concept with considerable structural lag in healthcare and policy development. To provide a historical context, a 20-year old in 2000 was more likely to have a grandmother alive than a 20-year old having a living mother in 1900 (Uhlenberg, 1996). The most dramatic increases in life expectancy were seen between 1900 and 1950, where advances in medical technology have nearly eradicated the most prevalent and deadly infectious diseases. Since 1950, the increases in life expectancy have plateaued to an annual increase of 0.1 years (Arias, Heron, & Xu, 2016). Thus, the prevalence of aging in our day-to-day lives is a historically novel concept and we are early in the attempts to understand how to address age-related health issues.

The expanding older adult population is expected to follow a more accelerated trend over the next 25 years with the arrival of the Baby Boomers and continued medical advances. The Baby Boomers are a cohort of Americans born following World War II, between 1946 and 1964, which represents a disproportionate amount of births compared to surrounding eras. In 2011, the first of the Baby Boomers celebrated their 65th birthdays and over the course of the next 19 years we will continue to see accelerated growth in this demographic with 26 percent of the total US population consisting of Baby Boomers (Administration on Aging, 2016). In the past decade alone we have experienced a 28 percent increase in the 65+ year old population with 36.6 and 47.8 million in 2005 and 2015, respectively (Administration on Aging, 2016). These accelerated trends are expected to continue up until 2040 when one in five Americans will be 65+ years (Administration on Aging, 2016).

In 2016, after reaching the age of 65 years one can expect to survive another 19.4 years on average or 84.4 years which is nearly double that of a 65 year old in 1900 (Administration on Aging, 2016) Therefore, once reaching the age of 65 today one could expect to live nearly another quarter of their lives. The combination of improved medical advances in the diagnosis, treatment, and management of age-related chronic illnesses and improved healthcare access to older adults through Medicare programs have likely contributed to recent life extension in older adulthood. However, there are three primary factors that are contributing to the unprecedented 'era of aging' that we will witness over the next three decades. Collectively, these include the increased likelihood of reaching 65+ years old, the arrival of the disproportionate population wave of the Baby Boomers in 2010, and life extension into advanced old age. These trends have contributed to individuals in the advanced old age cohort (85+ years) being the fastest growing demographic in the US, expecting to double by 2040 and triple by 2050 (Administration on Aging, 2016). This increasingly diverse cohort of older adults will come with challenges in identifying and appropriately addressing health burdens at the individual, community, and population levels.

Among this aging cohort is an increasingly diverse demographic with 22 percent of persons aged 65+ years coming from various racial/ethnic minority groups, income level, education, and health disparities. In 2015, non-Hispanic African American, Hispanic, and Asian/Pacific Islander populations made up the largest proportions of these minority groups at 9 percent, 8 percent, and 4 percent, respectively (Administration on Aging, 2016). The proportion of minority groups in older age is expected to continually increase from the current 22 percent to 28 percent in 2030 (Administration on Aging, 2016).

Within this increasingly diverse older adult cohort is the most educated and wealthiest older adult population to date. The percentage of older adults to have completed high school increased from 28 percent to 85 percent between 1970 and 2016 with one in four having a college degree (Administration on Aging, 2016). Compared to the preceding cohort, the Baby Boomers have greater wealth (Lusardi & Mitchell, 2007) and possess nearly 70 percent of all US disposable income (US News Report, 2015). However, there is wide variation in the incomes of the Baby Boomer cohort. Specifically, over one in three 65+ year old households report an annual income of over $75,000 per year, yet the individual median income is $22,887 with roughly 84 percent of older adults relying on Social Security benefits as a primary source of income (Administration on Aging, 2016). Furthermore, the Baby Boomers above the third quartile of total net worth have more than ten times the wealth of those in the first quartile (Lusardi & Mitchell, 2007).

It is important to note that the expanding diversity in an aging cohort may also contribute to a greater than expected occurrence of physical disabilities in the older adult community. Holmes and colleagues (2009) identified that race, gender, and education were predictive factors to the presence of self-reported physical limitations. The details and contributing theories of functional health in an aging population will be covered in more detail in the "Aging and Functional Health" section of this literature review. Prior to this, I will discuss the typical health burdens persistent among an aging population will be discussed.

Aging and Health

In the 20th century, life expectancy experienced its most rapid increase which came with a price as modern societies were witnessing a growing epidemic of age-related chronic disorders including heart disease, stroke, cancer, diabetes, Alzheimer’s, and frailty. Without a cure for these progressive diseases, medical technology responded by rapidly developing secondary medical interventions to detect, treat, and manage these co-morbidities in a disease-specific manner. In a ‘leaky boat’-style of disease management, survival of each specific disease improved with only modest advances in longevity as a novel age-related disorders backfilled the effect on mortality of the previous disease. Therefore, recent advances in longevity have led to the accumulation of multiple co-morbidities which can lead to years added in poorer health (Seals, Justice, & LaRocca, 2015), compromised physical functioning (Cesari et al., 2006), impaired quality of life, and an increased dependence for continued healthcare in later years (Crimmins & Beltran-Sanchez, 2010; Frey, 2010). The characteristics of some of these *geriatric syndromes* and their impact on functional health will be described in the following paragraphs.

Over half of all older adults will spend approximately one-quarter of their lives managing three or more co-morbidities (American Geriatrics Society Expert Panel on the Care of Older Adults with Multimorbidity, 2012; Administration on Aging, 2016). The most prevalent of these co-morbidities being cardiovascular disease (CVD) which has remained the leading cause of death in the US since 1921, claiming over 614,000 lives in 2014 (Centers for Disease Control and Prevention, 2015). Age is the primary determinant of CVD which can lead to cardiac hypertrophy, left ventricular dysfunction, increased arterial stiffness, and impaired endothelial function (Lakatta & Levy, 2003), all of which can influence cardiorespiratory fitness and functional status (Seals et al., 2015). This can in turn lead to a vicious cycle of further declines in physiological function with advanced trajectories to end-stage heart disease and the development of other co-morbidities.

Improved survivability and management of heart disease during the 20th century led to a reduced age-adjusted risk of heart disease mortality since 1935 (Centers for Disease Control and Prevention, 2012), but a subsequent onset of other chronic degenerative diseases of advanced age began to manifest like cancer, neurocognitive disease, and frailty. Cancer mortality rates began to progressively increase in 1969 as heart disease mortality rates declined and plateaued (Centers for Disease Control and Prevention, 2012). Although cancer was the second leading cause of death in 2014 claiming 591,000 lives, a current diagnosis is not considered a death sentence as it once was in previous decades. Of the approximate 1.7 million new cancer cases in 2014, approximately 66 percent are expected to live at least another five years, contributing to the 15 million cancer survivors living today (American Cancer Society, 2014). However, those in cancer survivorship are at an increased risk of other cancers, obesity, diabetes, CVD, osteoporosis, and functional limitations (Demark-Wahnefried Pinto, & Gritz, 2006).

Older adults have the highest prevalence of diabetes compared to any other age-group impacting between approximately 25 percent of those aged 65+ years (Center for Disease Control and Prevention, 2011). Diabetes in older adults is linked to increased risk of premature mortality, reduced functional ability, and increased risk of institutionalization (Brown et al., 2003). In particular, diabetes has a strong link to microvascular damage and classic cardiovascular disease, in addition to several other geriatric syndromes which can affect independent living and quality of life (Kirkman et al., 2012). Incident neurocognitive disorders like Alzheimer ’s disease and dementia are twice as likely to occur in older adults with diabetes compared to age-matched individuals without diabetes (Lu et al., 2009). Further, the progressive age-related decline in muscle mass and strength may be exacerbated by complications related to diabetes. In BMI- and age-matched individuals, those with long-standing diabetes had lower muscle strength per unit muscle mass than those with diabetes for shorter durations or (Park et al., 2006). Similarly, those with higher blood sugar had compromised muscle mass compared to those without diabetes or with better glycemic control.

Osteoporosis, or a progressive age-related decline in bone mineral density, is linked to approximately 1.5 million fractures per year, including 300,000 hip fractures and 700,000 vertebral fractures (Keen, 2003). Between the ages of 65 and 95 yeas the incidence of hip fractures increase from 1.6 per 1000 to 35.4 per 1000 (Jacobsen et al., 1990). As a geriatric syndrome, osteoporosis has become a major public health issue linked to an estimated $22 billion in direct medical costs in 2008 (Blume & Curtis, 2011). Hip fractures often lead to further complications including chronic pain, reduced PA, depression, unintentional weight loss, and premature mortality (Rolland et al., 2008). Following hip fracture, mortality risk is increased by 35 percent and 10 percent at 1 and 2 years, respectively (Todd et al., 1995; Lyles et al., 2007). While osteoporosis can increase the susceptibility to a fracture due to more brittle bone, the accompanying limitations for frailty including reduced strength and motor function can compound the likelihood of a fall leading to a fracture (Rolland et al., 2008). Although osteoporosis is not a marker of frailty, a frail individual is both at higher risk of osteoporosis and falls leading to fractures. This has led to a call for therapeutic interventions targeting this triad of frailty, osteoporosis, and hip fractures.

Neurocognitive disorders like dementia and Alzheimer’s disease present a progressive deterioration of memory, language, and other cognitive functions that can lead to loss of independence and rapid decline in health. Approximately 5-7 percent of those over 60 years old have dementia (Prince et al., 2013) with the prevalence increasing in advanced age to roughly one in three persons dying with dementia (Brayne et al., 2006). There are no current pharmacological interventions to cure or reverse dementia, but diabetes and frailty are identified as modifiable contributing risk factors for neurocognitive decline (Kojima et al., 2016). In a cohort of 1,575 community-dwelling Chinese older adults, there was an increased prevalence and incidence of cognitive impairment among those identified as pre-frail or frail (Feng et al., 2016). Approximately 40 percent of older adults that were identified as frail were cognitively impaired and the co-existence of cognitive impairment and frailty led to increased risk of incident neurocognitive disorders, suggesting an intertwined relationship between cognitive and physical impairments (Feng et al., 2016).

With a primary focus on the treatment of age-related diseases, rather than the prevention of age-related diseases, the underlying physiological decline continues leading to an increased presence and accumulation of multiple comorbidities. The management of multiple comorbidities can be overwhelming and may indicate an increased risk toward a frail phenotype. In a cross-sectional evaluation, Cesari and colleagues (2006) identified a significant link between the presence of comorbidities and reduced performance of physical function in community-dwelling older adults. Among these individuals, typical physical traits are present that identify a frail phenotype including unintentional weight loss (10 lbs in one year), self-reported exhaustion, poor strength, poor gait speed, and low PA (Fried et al., 2001).

Frailty is a clinical syndrome to describe the physical manifestation of a progressive age-related decline in physiological functioning (Fried et al., 2001, Seals et al., 2015). Being identified with frail phenotype is independently predictive of adverse outcomes including incident falls, worsened mobility, activities of daily living (ADL) disability, hospitalization, and mortality within 3-5 years (Fried et al., 2001). Aside from age, disability is the strongest predictor for adverse outcomes (Guralnik, Fried, & Salive, 1996). Fried and colleagues (2001) suggest that frailty not be identified as a comorbidity, but co-morbidities are a risk for the development of frailty and disability is an outcome of frailty. With the 85+ year old population expected to triple over the next 35 years, there will be approximately 17.9 million people at increased risk for functional limitations and loss of independence (Administration on Aging, 2016).

In summary, the variation and dispersion of age is continually increasing in the 65+ year old cohort. The presence of medical technological advancements have allowed for greater detection and effective treatment of specific ailments, leading for greater delay and evasion from mortality. However, the underlying aging process affecting physiological function remains following the successful implementation of cardiovascular, cerebrovascular, and oncological treatment. This has led to a growth in the diagnosis of physical and cognitive impairments that limit functional capacity, compromise independence, and increase dependence on long-term care supports and services. The following section will highlight the societal and economic impact from a rapidly expanding older adult population that is reaching advanced age and more prone to functional decline.

Socio-Economic Impact of Aging

Projected total costs from CVD in the US are expected to nearly double over the next 15 years from $650 billion to $1.2 trillion (Mozafarrian, 2015) and direct cancer-related costs are projected to reach $174 billion by 2020 (costprojections.cancer.gov). Fortunately, this financial burden does not lie directly on older adults as nearly 100 percent of 65+ year olds have been covered by hospital insurance since the implementation of Medicare in 1965.

Current social healthcare policy states that individuals over the age of 65 years are eligible for Medicare which is a federal health insurance program to help cover the costs of medical expenses in a population burdened by multiple age-related diseases. In 1965, Medicare was launched to help relieve the individual financial burden of out-of-pocket spending from serious and recurring medical conditions in late life. Prior to Medicare being enacted, only 25 percent of older adults had meaningful private health insurance and 30 percent of older adults were living in poverty (Lind, 2012). In 2015, 55.5 million people were covered by Medicare which currently makes up 14 percent of the federal budget and with projections to increase outlays from $632 billion to $1.1 trillion between 2015 and 2024 (Kaiser Family Foundation, 2015).

Approximately 70 percent of people will rely on one form of long-term care at some point of their life after reaching the age of 65 (www.longtermcare.gov, accessed Nov 20, 2016) and will require approximately three years of long-term care over the course of their lives (Kemper et al., 2005). The reliance for LTSS aren’t evenly spread, with about a third of people needing little or no care, and about 20 percent requiring care for five or more years with age, gender, health, and disability status contributing to the time of entrance and length of stay in these facilities (Kemper et al., 2005; U.S. Department of Health and Human Services, 2012). However, one in five older adults will rely on LTSS lasting up to five or more years which can contribute to exhausted personal savings and forced impoverishment of disabled older adults until becoming eligible for Medicaid (Kemper et al., 2005; U.S. Department of Health and Human Services, 2012).

Costs related to LTSS are primarily dependent on where, how long, and from whom the services are received. In general, informal care received in the home or community is often performed for free or at a much reduced rate compared to formal care services that may be received in skilled nursing facilities. Traditionally, a majority of LTSS responsibilities have been provided through informal care in the homes and community by immediate family members and friends. The value of these informal care services nearly doubles the actual amount spent on LTSS with approximately $450 billion provided at no cost by families and other informal caregivers versus $219 billion spent on services for pay (Feinberg, Reinhard, Houser, & Choula, 2011). However, changes in family dynamics over the past century have resulted in a growing dependence on formal LTSS.

The reduced ratio of potential caregivers due to cohort characteristics and changing occupational roles of traditional caregivers present significant barriers to informal care delivery. For example, Baby Boomers entered prime caregiving years (44-64 years) between 1990 and 2010 with a caregiver ratio of 7:1, but when transitioning into care-receiving years (65+ years), estimates of the caregiver ratio are expected to drop to 4:1 in 2030 then to 3:1 in 2040 (Redfood, Feinberg, & Houser, 2013). Also, women have traditionally taken on more caregiving responsibilities and represented a majority (58 percent) of informal care (The Henry J. Kaiser Family, 2013; Moody & Sasser, 2011). But trends are showing increased women’s participation in the labor force and as a significant source of income in the family suggesting there is, and will be, less time for women to provide informal caregiving throughout the day (Li & Rafferty, 2006). With a changing family dynamic that is less likely to provide informal care support, older populations are more likely to enter institutional care settings that will drain personal assets before being placed on impoverished support structures that were not intended to be used for long-term care.

When informal care is not available, older adults will have to rely on formal LTSS which primarily consists of care in institutionalized settings or the use of home-care aides. Long-term care is typically paid for by private long-term care insurance (8 percent), out-of-pocket (19 percent), other public options like the Department of Veteran Affairs (21 percent), or through Medicaid benefits (51 percent), but not through Medicare (Reaves and Musumeci, 2015). Contrary to popular belief, Medicare does not cover all medical expenses. In particular, and relevant to this literature review, Medicare does not cover LTSS which often include custodial services for personal needs and assistance with tasks of everyday living. Long-term supports and services are covered under Medicaid; however, an individual asset limit of $2000, and $3000 for couples, often leaves middle-class families without a “public safety net” for the high costs of LTSS.

The cost of formal LTSS can far exceed the income and personal savings of older adults. The average retirement savings of Baby Boomers is approximately $75,000 (Genworth, 2012) with a median household income of $27,612 and $16,040 for males and females, respectively (Administration on Aging, 2016). These finances can be immediately overwhelmed by the median annual costs of skilled-nursing facilities at $91,250 in 2015 (Administration on Aging, 2016). It is estimated that a 65 year old will require an average private savings of $50,000 is needed to cover the long term care (Kemper et al., 2005). Of those who enter skilled-nursing facilities as private pay customers, 70 percent become impoverished within three months, and 90 percent reach poverty within a year (Moody & Sasser, 2011).

Because of the high costs associated to LTSS and the required extended stays for those receiving this type of care, the allocation of funds to those Medicaid eligible is disproportionate. Nearly 30 percent, or $128 billion, of the entire Medicaid budget which includes impoverished and disabled individuals of all ages is spent on LTSS for the elderly (Reaves and Musumeci, 2015). Further, 87 percent of all Medicaid funding on the elderly is spent on LTSS for only one-third of the nearly six million elderly Medicaid enrollees (Kaiser Commission on Medicaid and the Uninsured, 2011).

The current long-term care policies to address the socioeconomic challenges that face older adults that may rely on long-term care are long outdated, but efforts are being made to address the personal, state, and national costs of LTSS. In particular, a U.S. Supreme Court ruled in 1999 that there was an unjustified segregation of individuals with disabilities into institutionalized settings where confinement to these facilities diminished quality of life and that community-based services should be accommodated. The ruling has had a profound affect among those that are Medicaid eligible with home- and community-based Medicaid waivers nearly tripling since 1995 and for the first time accounting for the majority of LTSS in 2013 at 51 percent (The Kaiser Commision on Medicaid and the Uninsured, 2015). However, those relying on private out-of-pocket spending for LTSS are still at an exceedingly high risk of future impoverishment unless changes are made to long-term care insurance policies for older adults.

Summary of Aging of America

The 65+ year old population is expected to double and the 85+ year old population is expected to triple by 2040. With medical technology constantly improving the survivorship of those afflicted by CVD and cancer, there is an increasing presence of older adults that have escaped premature mortality but are experiencing the physiological decline of advanced old age. The presence of physiological decline significantly affects the ability to perform ADLs and subsequent risk of institutionalization and the increased costs associated with LTSS. Actions taken to improve the functionality of older adults will improve the quality of life of older adults, while also providing a financial incentive for those at the individual, state, and national levels.

Aging and Functional Health

Introduction

On average, the age at which physical limitations are reported occurs later in life than ever before (Holmes et al., 2009). However, greater numbers of individuals are reaching older adulthood and surviving into advanced old age. The previous section of this literature review introduced topics related to a novel aging population and the social and economic impact of age-related health issues which require long-term care. Altering how long-term care is privately and/or publicly delivered, managed, and financed may alleviate some socioeconomic issues, but the issue of an aging physiological system remains and will continue to affect quality of life. Geroscientists have approached this issue from a standpoint of targeting a reduction in time spent under long-term care by preventing, delaying, and reversing poor health and functional limitations in older adulthood. Preventing or reducing long-term periods of morbidity and disability will provide a dual effect of relieving the healthcare burden and improving the lives of older adults.

To better understand how to develop interventions to reduce functional limitations and the burden of long-term care, we must gather a better understanding of aging and functional health. The following section will define function and disability, methods to assess functional health, prevalence of functional limitations, physiological mechanisms linked to functional decline, and evidence for the plasticity of physical functioning.

Defining Function and Disability

Physical tasks can encompass a wide range of capabilities including tasks like running a marathon to everyday tasks like getting out of bed or grasping a coin. The ability to perform along a diverse and wide-ranging continuum of complex human movement is determined by the functional reserve capacity of an individual. While the inability to complete a marathon isn’t likely to affect areas of everyday life or present other clinical risks, the inability to rise from a chair may indicate a low-reserve in functional capacity and a need for assistance in performing other daily tasks. Individuals experiencing the latter scenario represent a clinical population with increased risk for disability, adverse events, and institutionalization (Fried et al., 2001). When functional limitations present themselves as clinical outcomes in an epidemic fashion, there must be national and international consensus on definitions and terminology.

The International Classification of Functioning, Disability, and Health (ICF) presented by the World Health Organization (WHO) provide a multipurpose classification system to serve various disciplines. The ICF suggests a multi-dimensional and interactive model for disability and functioning which is shown in Figure 1. In summary, a balance between function and disability can include impairments (deficits in body structures or function), activity limitations (difficulty in performing tasks or actions), and participation restrictions (problems with social participation) which are influenced by health conditions, environmental factors, and personal factors (WHO, 2001). Disability denotes the negative aspects of this interaction where limitations occur and function represents the positive or neutral aspects of this interaction, or no disability. Along the disability continuum, there is variation in the ability to complete tasks with ease or difficulty compared to an absolute inability to perform a task which would be identified as a disability. This is identified as the functional reserve capacity of an individual. Thus, functional limitations that lead to difficulty in performing physical tasks represent a moment along the disablement process with disability serving as an outcome.

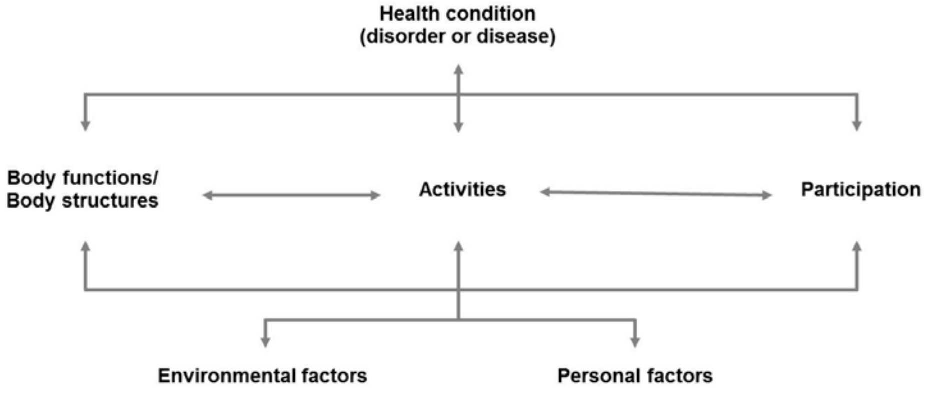

Figure 1. Interactions between the components of International Classification for Functioning, Disability, and Health (WHO, 2001)

Drawing a line for ‘disability’ versus ‘no disability’ depends on the purpose of doing so which has led to various identifiers. For the purposes of this literature review, we are concerned with a broad segment of pre-clinical to clinical levels of physical functioning along the disablement continuum. Specifically, mobility limitations that are linked to the impairment of executing tasks linked to independent living.

Assessment of Physical Function

While functional impairments or disability have been traditionally assessed through self-report, there is growing importance emphasized on including measures of physical performance to supplement and gain a more objective determination of functional capacity and risk (Guralnik, Fried, & Salive, 1996). Surveys can be administered with relative ease and at a low-cost while gathering information from a diverse range of functional capabilities. However, surveys rely on subjective self-reporting that may be subject to bias, memory lapse, under-/over-estimation of functional capabilities, and lack the sensitivity to detect early signs of functional limitations.

Mehta and colleagues (2007) identified significant differences between self-reported physical limitations and objectively measured physical performance across a 5-year span were linked to anxiety symptoms related to aging. Physical performance measurements are considered objective, or less susceptible to bias from participants. Furthermore, epidemiological and experimental studies have suggested that the use of physical performance measures is more sensitive to change in functional health across time, especially when detecting early functional decline (Mehta et al., 2007). This is largely due to the inability of self-reported measures to discriminate functional health among non-disabled older adults. Therefore, both surveys and physical performance measures provide distinct benefits and if possible should be used together to gather a collective portrait of functional health.

Important to the assessment of physical function and severity of activity limitations, the ICF presents a key difference between performance and capacity. Performance describes the ability of an individual to execute a task in a free-living environment and capacity describes their ability to execute a task in a controlled environment (WHO, 2001). Applying this definition to measures of functional health, the use of surveys with self-reported ability to perform various activities in the free-living environment are intended to assess performance. Alternatively, objective measures that utilize standardized assessments like chair rise time or gait speed are intended to assess functional capacity. This adds to the recent emphasis of utilizing both measures to gather a more descriptive portrait of functional health. Also, the discrepancy between environmental demands (performance) and intrinsic capabilities (capacity) determines true disability and underlines the utility of either improving capacity, modifying the physical environment, or both to enhance execution of tasks in free-living scenarios.

Additionally, public health officials are increasingly becoming aware that statistical significance does not often translate to clinical significance. Statistical significance may not be a clear indicator of clinical effectiveness when small sample sizes and measurement variability may influence a statistical result. For example, a study using a large or very large sample and/or an instrument with minimal variability may yield statistical significance by manipulating power. However, the magnitude of change from baseline may translate to clinically relevant outcomes. Therefore, clinicians and public health professionals may be interested in obtaining the direction and magnitude of treatment outcomes even with non-significant statistical results.

Clinicians and clinical researchers have not settled on a single definition of clinical significance, which is distinct from clinical relevance. Examples of interchangeable definitions commonly reported include minimally clinically important difference (MCID), clinically meaningful difference (CMD), or minimally important change (MIC) all represent similar outcomes that public health professionals may be interested in.   In general, these definitions all represent a smallest change in an outcome score that would result in an “important” change that is noticeable by the practitioner or patient (Page et al., 2014).

Self-report assessment. Painter and colleagues (1999) classified physical functioning into two primary categories: 1) basic actions and complex activities necessary to maintain independence and 2) those discretionary to independent living, but impact quality of life. These included ADL, instrumental activities of daily living (iADL), and physical performance measures. Activities of daily living are the most frequently used indicators of disability, which include activities like bathing, dressing, transferring from a bed to chair, using the toilet, or eating (Katz et al., 1963). Instrumental activities of daily living tend to be more complex and difficult tasks that are necessary for independent living, including activities like shopping, housekeeping, preparing meals, laundry, transportation, managing medications, and handling finances (Lawton & Brody, 1969). The greater number of ADLs or iADLs that have been identified as difficult or an unable to complete alone indicates more severe disability.

In recent years, other functional indices have been utilized as advanced functioning indicators to forecast future physical limitations and disability risk. Advanced functioning surveys include questions about the difficulty or inability in performing tasks like walking up flights of stairs, walking multiple city blocks, lifting a 10 lb item overhead, and performing vigorous-intensity PA (VPA). In the geroscience community, there has been growing recognition that responses to performing ADLs or iADLs do not discriminate well for individuals with pre-clinical disability. Also, these functional domains (ADLs, iADLs, and advanced functioning assessments) provide a means of stratifying individuals along the disablement process and serve as important prognosticators of frailty, institutional care needs, and mortality in 2-4 years (Carey et al., 2004; Lee et al., 2006).

The RAND 36-Item Health Survey (SF-36) is the most commonly used self-report instrument of physical functioning. It is a self-administered test that includes eight domains of health, including physical function as a subdomain that is scored on a 0 to 100 scale. Walters, Munro, and Brazier (2001) identified the SF-36 as a practical and valid method of assessing physical functioning in large scale community-dwelling older adults. However, Wittick and colleagues (2003) identified that although the SF-36 physical functioning scale was strongly correlated with treadmill walking time, both disability status and lower mental health scores had a stronger effect on self-reported physical function than physical performance measures. Therefore, the use of objective performance-based measures of physical functioning should be used to supplement the SF-36 instrument.

The Late-Life Function and Disability Instrument (LLFDI) is a more comprehensive assessment of physical functioning that was specifically developed for community-dwelling older adults. Therefore, this assessment includes a wide variety of life tasks along the disablement continuum without the presence of ceiling or floor effects (Denkinger et al., 2008). The LLFDI has been shown to have concurrent validity with the SF-36 physical function subscale (Jette et al., 2002) and convergent validity with various performance-based assessments (Denkinger et al., 2008). Furthermore, the predictive validity and responsiveness to two years of aging in community-dwelling older adults was comparable between the LLFDI and performance-based measures that serve as proxy measures for overall functional capacity (Beauchamp et al., 2014). For instance when self-report is the primary outcome available, the LLFDI may serve as an optimal instrument of assessing global physical functioning.

Performance-based assessment. Performance-based instruments for physical function can include a wide variety of simulated tasks that capture physical performance or proxy measures that are performed in a controlled setting to identify physical capacity. For example, the Continuous Scale of Physical Functional Performance test (CS-PFP-10) is an intensive instrument that includes a broad range of activities including both upper and lower body strength and endurance vital for living independence. The test consists of 10 ADLs which were specifically designed to assess the building blocks of physical function in to five domains: lower body strength, upper body strength, upper body flexibility, balance and coordination, and endurance. The reliability and validity of the CS-PFP-10 are excellent (Cress et al., 1996; Cress et al., 2006), with a score <57 on a scale of 0 (poor function) to 100 (excellent function) indicating non-independence (Cress et al., 2003). However, even as an abbreviated version of the previous instrument that used 16 tasks, the ability to perform this test on large scale population representative samples is unlikely.

In an effort to find middle ground, proxy measures of performance-based instruments have been utilized that focus on the demands of the previously mentioned building blocks of function. The Short Physical Performance Battery (SPPB), timed up-and-go (TUG), usual gait speed (UGS), hand grip strength, leg extensor strength, chair rise, 400-meter walk (400W), and 6-minute walk are abbreviated tests that are most commonly used to their ease in administering and low-cost.

The performance-based measures vary in degrees of difficulty and incorporate different domains of physical function, but primarily include muscular strength and endurance, balance, and coordination. The SPPB is the most widely used performance-based physical function instrument and has been identified as having predictive validity for those with moderate to high levels of mobility disability, institutionalization, and mortality (Guralnik et al., 1994). The SPPB consists of three separate subscales for balance, gait speed, and chair rise ability each scored on a scale of 0-4 to provide a total score for function 0-6 as poor performers, 7-9 as moderate performers, and 10-12 as good performers. The balance test uses a hierarchy of more difficult standing positions, gait speed is timed to complete 2.44 meters, and the time to complete to complete five unassisted chair-to-stand movements from a chair. Substantial meaningful change in the SPPB is listed as an improvement by 0.99-1.34 points in the total score.

Usual gait speed includes the participant performing a walking task over various predetermined distances. The observer can collect time and make observations about the performance, including sway. Gait speeds of all distances are significantly positively correlated with self-rated health and depression (Kim et al., 2016). Perrera and colleagues (2006) identified small and substantial meaningful change in usual gait speed as 0.05 and 0.10 meters per second, respectively, in community-dwelling older adults.

The chair rise test can include a 30-second sit-to-stand (30STS) maximal repetition or a time to completion of five-time sit-to-stand (5xSTS) movements. Both tests have been identified as reliable and valid measures of physical function in community dwelling older adults (Jones et al., 1999). For the 30STS, a change in score of at least 5+ is considered a major improvement in chair rise ability (Wright et al., 2011) and in the 5xSTS a change in time of 2.3 seconds or greater represents a MCID (Meretta et al., 2006).

The TUG test is an updated version of the ‘get-up-and-go’ test that is a quick, easy, and widely used measure of physical performance among older adults. The test incorporates a single repetition of the chair rise test and a 3-meter gait speed assessment into one test. During the test, the participant rises from a seated position and walks to a designated point 3-meters from the chair and returns to the chair to complete the task in a seated position. The TUG has been identified as a reliable and valid measure of lower extremity function, mobility, and fall risk (Brooks et al., 2006, Lin et al 2004, Steffen et al., 2002). In particular, a TUG time above 13.5s in a healthy older adult is a strong indicator of poor mobility [Herman et al., 2011]. Also, meta-analysis has identified that the TUG is moderately related to cognitive ability, specifically executive function, where the prior tests are not. Therefore, this measure serves as a good indicator of physical performance in a healthy, community-dwelling older adult population.

Recent meta-analysis has identified that the TUG has a limited ability to predict falls in community-dwelling older adults and should not be used in isolation to predict fall risk, but should be part of a battery of tests that can more accurately predict falls [Barry et al., 2014]. The MCID for the Timed up and go test is 1.4 seconds (Wright et al., 2011). In contrast to the sit-to-stand test, TUG incorporates characteristics of power, balance, and gait into one test and is less likely to suffer from a ceiling effect [Herman et al., 2011]. Different cut-points are available to provide indicators of mobility for various clinical populations, with a cut-off score > 13.5 sec indicating an elevated risk for falls in a small sample of community-dwelling older adults (Shumway-Cook, Brauer, & Woollacott, 2000).

Representative measures of overall muscle strength include hand grip strength and lower limb extensor strength. Decreases in muscle mass and quality of force development can impact the ability to perform the complex performance-based measures previously mentioned. For example, a certain level of muscular strength and endurance is needed to erect the body from a seated position and maintain upright positions without fatigue. Measures of overall body composition, muscle fiber quality, or isometric dynamometry of large muscle systems can be burdensome. Hand grip strength can be performed using portable units and provide simple and affordable options of assessing strength with good reliability and predictive validity compared to other more complex strength measurements (Bohannon, 2008). Handheld devices that measure leg strength that provide portability, simplicity, and affordability come with a sacrifice of accuracy, but have been identified as reliable and valid measures of lower limb strength (Arnold et al., 2010).

The inability to complete a 400W test within 15 minutes without sitting or receiving assistance has been identified as a major mobility disability (Fielding et al., 2011). The 400W is a much more difficult task than a typical usual gait speed or chair rise because it requires a prerequisite of muscular strength, endurance, coordination, and balance with cardiorespiratory fitness. The 400W tests high in test-retest reliability for inability to complete the test and is highly predictive of mobility limitations (Rolland et al., 2004). Kwon et al. (2009) identified that an improvement of 20-30 seconds and 50-60 seconds in the 400W represented minimum and substantial meaningful change, respectively, and Beauchamp et al. (2015) reported a minimum detectable change of 1.25 minutes.

Recent efforts have been made to improve performance-based measures. In particular, several performance-based physical function assessments suffer from floor and ceiling effects. Cress and colleagues (2010) proposed combining data from instruments of varying degrees of difficulty to provide a continuous scale using item response theory (IRT). Also, various measures rely solely on time to completion without taking into account postural modifications to improve completion or wobble in the gait which cannot be detected by a stopwatch. Accelerometers are more frequently being used to collect physiological data and have been shown to exhibit sensitivity to previously undetectable changes in physical function (Regterschot et al., 2014). These body-worn sensors are placed on various parts of the body, depending on the test, and assist in the measurement of the bodily movements. The technology is currently being developed for the use of identifying clinically relevant functional outcomes from interventions and there is not yet a database established to strengthen the detection of high risk non-frail individuals. More research is needed, but accelerometer-assisted functional tests may prove to be a more sensitive identifier of frailty risk in pre-clinical older adults than current performance-based measures.

A novel means of assessing physical functioning and mobility capability includes the measurement of PA behaviors. While there is strong evidence that PA helps preserve cognitive and physical functioning in old age (Pahor et al., 2014), the ability to walk is significantly linked to life-space mobility (Viljanen et al., 2015). Life space-mobility is identified as the spatial size a person purposefully navigates in the physical environment on a daily basis (Baker et al., 2004). Free-living PA can be assessed through survey, or more recently objectively in combination with activity monitors. Accelerometers provide a reliable quantification of PA and are a feasible and sensitive method of measuring PA in free-living environments of older adults (Pruitt et al., 2008, Copeland et al., 2009). The addition of global positioning systems (GPS) or WiFi signal detections to activity monitors is likely to enhance measurement of life-space mobility. The assessment of free-living PA and life-space mobility may provide vital information for a physical functioning model that describes the relationship between physical capacity and physical performance.

A selection of an assessment for physical function is best determined by the research question and the functional capacity of the sample included in the study. If performing interventions focused on affecting the building blocks of physical functioning including strength, endurance, coordination, balance, and flexibility then performance-based tests should be emphasized over self-report. Lastly, one or more self-report instruments may be needed with varying degrees of functional assessment depending on the sample population.

Prevalence of Functional Limitations and Disability

Population-based surveillance data and population-representative observational studies have identified heterogeneity in age-related functional limitations. Specifically, while age is a primary predictor of functional limitations certain modifiable and non-modifiable personal characteristics can augment risk and trajectories in age-related physical decline. Because physical function is predictive of long-term care needs, prevalence rates of functional limitations and age-related disability aid in projecting potential future shortcomings and highlight demographics that might be at highest risk.

Among the Cardiovascular Health Study cohort the prevalence of frailty was approximately 7 percent and 30 percent of those at least 65 years old and 80 years old, respectively (Fried et al., 2001). Among community dwelling older adults, approximately 11 percent of those aged 65+, 25 percent of those aged 85+, and 50 percent of institutionalized older adults were identified as being frail (Collard et al., 2012; Kojima, 2015). Age-related declines in physiological function indicate an increased risk of developing a frail phenotype coinciding with mobility disability, loss of independence, hospitalization, institutionalization, and premature mortality in later stages of life (Fried, Ferrucci, Darer, Williamson, & Anderson, 2004; Walston et al., 2006). According to the 2004 Long-Term Care Survey which is a population-representative cohort of community and nursing home residences, between 6 and 9 million of older adults were identified as frail depending on various indices of frailty (Cigolle et al., 2009). If the prevalence rates of frailty remain consistent today, then it is projected that approximately 13 million older Americans will experience heightened vulnerability to disability or death.

The National Health Interview Study is another population-representative surveillance dataset that identified the impact of aging and disease burden on physical limitations. Physical limitations were identified as higher functioning activities like walking three city blocks, walking up 10 stairs without resting, and standing on your feet for two hours. In this cohort, adults aged 80+ years are 2.5 times more likely to experience one or more physical limitations than 50-59 year olds (Holmes et al., 2009). In 2013, nearly one-third of community dwelling Medicare recipients aged 65 and older reported difficulties in performing ADLs and 12 percent with one or more iADLs (Brault, 2012). This represents a population of 13 million older Americans that are at immediate risk for disablement and loss of independence.

In 2010, approximately 56.7 million people lived with disabilities in the US, which represents nearly one-fifth of the noninstitutionalized civilian population (Brault, 2012). This data from the 2010 US Census classified disability as non-severe (difficulty doing the activity) or severe (unable to perform the activity). Among all older adults, one in three report having at least one disability, one in four report ambulatory difficulty, and one in six report an independent living disability (Administration on Aging, 2016).

The percentage of individuals with non-severe disability or severe disability increased with every decade beyond the age of 15 years with accelerated growth after 55 years. Prevalence for non-severe and severe disability between the ages of 55-64 years is 28.7 percent and 20.4 percent, respectively. Between the ages of 65-74 there is a relative increase of in non-severe and severe disability by 48 percent and 45 percent, respectively, with both categories increasing 2.5-fold for those greater than 80 years when compared to 55-64 year olds.

Those using nursing homes, residential care facilities, or home care services is expected to increase from 15 million to 27 million between 2000 and 2050 (US Department of Health and Human Services, 2003). Among those that reach the age of 65, approximately two in three will require long-term care services in their lifetime (Kemper, Komisar, & Alecxih, 2005-2006) and a 46 percent chance of spending time in a nursing home (Spillman & Lubitz, 2002). Current population statistics have identified that 2.7 percent of people aged 65+ lived in residences with at least one supportive service available and 3.5 percent lived in institutional facilities (Administration on Aging, 2016). The likelihood of living in an institutional setting increase with age where one percent of 65+ year olds and 10 percent of 85+ year olds residing in an institutional setting (Administration on Aging, 2016). Of the older adult population that remains in the community, approximately one-in-three have substantial long-term care needs with at least three ADL limitations (The Henry J. Kaiser Foundation, 1999). For those over 65 years and residing in nursing facilities, approximately 95 percent are dependent in one or more ADL and 81 percent with three or more ADL (Administration on Aging, 2016). Approximately half of all residential and nursing care recipients are at least 85 years old (Harris-Kojetin, et al., 2016), which is of considerable importance since this will be the fastest growing age-group over the next four decades.

Population representative data have identified consistent associations between functional limitations and disability based on demographic characteristics. Aside from age, other key characteristics that have been predictive of disability include gender, income, education, and ethnic minorities. Frailty prevalence which is predictive of mobility limitations and disability can be stratified by different sociodemographic and chronic disease profiles with oldest of the old, women, and African Americans experiencing elevated risk of frailty (Hirsch et al., 2006). Holmes et al. (2009) identified less advantaged groups reported functional limitations at earlier ages. Specifically, non-Hispanic black adults between the ages of 50-59 (24.1 percent) reported physical limitations at the same prevalence rates as non-Hispanic white adults between the ages of 60-69 (24.4 percent) (Holmes et al., 2009). When splitting this racial category by gender, women were more likely to report a physical limitation in each age group and within each racial category. The gender discrepancies widened with increasing age with longitudinal studies attributing this widening effect to women living longer than men after becoming disabled (Strawbridge et al., 1992). Regarding education, those between the ages of 50-69 experienced a

2-fold increased prevalence of reporting a physical limitation compared to those with a high school degree cation or higher. This effect of education was evident in both non-Hispanic white and black adults and the gap between educational statuses narrowed with increasing age.

The presence of multimoribidity may help explain the discrepancies in presence of physical limitations among those that are from disadvantaged populations. On average individuals from more deprived areas experience the onset of multimorbidity 10-15 years earlier than more affluent areas (Barnett et al., 2012). Cesari and colleagues (2006) identified a significant association between the presence of comorbidities and physical limitations. Thus, disability as an outcome may serve as an indicator of overall disease burden which is represented earlier in disadvantaged populations. Interestingly, the effect of PA on the prevention and treatment of multimorbidity and premature mortality has been investigated for decades with strong evidence for health benefits (US Department of Health and Human Services, 2008). Because of the vicious cycle between multimorbidity and disability, PA has been identified as a means of intervention to compress morbidity, disability, and mortality risk.

In summary, increased age is linked to greater prevalence rates of frailty, physical limitations, and disability in the population. While age exerts a primary influence on the prevalence rates of physical limitations in a population, individual demographic characteristics like gender, race, and education can influence the onset by a decade or more. Thus, there is heterogeneity in how we age that can be predicted and modified based on behavioral factors.

Physical Changes with Aging

Aging is a natural biological phenomenon and the primary driving force of omnibus physiological decline in older adults. Age-related reductions in physiological functioning contribute to development of functional limitations, increased risk of chronic diseases, disability and frailty, loss of independence, reduced quality of life, and mortality (Seals, Justice, & Larocca, 2015). Therefore, the physical traits from aging present the primary influence of the problems discussed in this literature review up to this point. Specifically, the progressive muscular impairment and accumulation of fat mass with increased age present a syndrome susceptible to comorbidity presence and mobility limitations. In general, there are four different body composition phenotypes: healthy, sarcopenic, obese, and sarcopenic obese (Lee, Shook, Drenowatz, & Blair, 2016). While the mechanisms for these trajectories in physical traits are not fully understood, the prevalence of these physical traits and relationships with other predictive variables are.

Sarcopenia. Sarcopenia is a multifaceted and naturally occurring age-related process that leads to a gradual 1-2 percent annual decline in muscle mass (Frontera et al., 2000) with a curvilinear decrease around 70 years of age (Pollock et al., 1997). Whole muscle weakness is present in aging and is predominantly accounted for by the reduced muscle mass and myofibrillar content present with muscle fiber loss and atrophy. Longitudinal changes in muscle mass suggest an annual 1-1.5 percent decrease in muscle strength beginning in the fourth decade of life (Frontera et al., 2012). Therefore, it is both the quantity and quality of the muscle fibers that contribute to the loss of muscle impairment.

Both cellular senescence and skeletal muscle disuse provide distinct and compounding influences on physiological reserve (Frontera et al., 2000) and the functional capacity to perform ADLs in the elderly (Seals, Justice, & LaRocca, 2016). Loss of strength in old age is primarily accounted for by physical traits including reduced muscle mass and myofibrillar content from progressive fiber loss and atrophy, characterized by the selective loss of fast-twitch muscle fibers

(Nair, 2005). The physical traits are attributed to reduced testosterone release and the chronic presence of sub-clinical inflammation with aging tend to tilt muscle to a catabolic state, reduced satellite cell number and activation in fast twitch muscle fibers, reduced myosin concentration in aging, suggesting older muscle fibers have reduced cross bridge potential (Frontera et al., 2012).

The muscle wasting of sarcopenia is measurable and based on lean body mass, grip strength, and gate speed (Cruz-Jentoft et al., 2010). The age at which these measures become clinically relevant are presented with inter-individual variability with some experiencing modest changes and other experiencing severe mobility limitations in early older adulthood. A genetic cause for increased susceptibility has not been identified with confidence, but external factors play a strong role and in particular PA habits (Daly et al., 2008). Immobilization, which can include habitual increases in prolonged sitting and lack of PA, further exacerbates reduced myosin concentration in muscle fibers (Frontera et al., 2012). This lack of neuronal stimulation of the muscle is believed to hasten the atrophy of the muscle with accompanying losses of strength and power (Rygiel, Picard, & Turnbull, 2016).

Obesity. Obesity is identified as an abnormal accumulation of excessive body fat and broadly measured as a body mass index (BMI: ≥ 30 kg/m^2). Age has been identified as a primary determinant of weight variation with a general trend of weight gain with increasing age until late life where it plateaus or declines (Thorpe and Ferraro, 2012). Obesity is linked to the presence of several comorbidities listed in the previous section with a two-fold increase in mortality risk in adults over the age of 50 compared to younger adults (Thorpe and Ferraro, 2012). As a caveat, the period of plateau and decline in late life, where unexpected loss in body weight and BMI is a common final pathway to frailty and mortality in individuals with end-stage heart disease, lung disease, kidney disease, cancer, AIDS, neurological disease, and advanced old age (Ades and Savage, 2010). Proposed causes for age-related weight gain and fatness include progressive declines in PA-related energy expenditure (PAEE) and reduced metabolic rate (Stenholm et al., 2008).

Sarcopenic obesity. When progressive loss of muscle mass and strength is accompanied by a presence of abnormal fat accumulation, this is termed sarcopenic obesity. As previously described, longitudinal studies have identified that weight gain or body fat progressively increases up to the seventh decade of life (Droyvold et al., 2006), where muscle mass slowly declines after the age of 30 years and accelerates in later years (Frontera et al., 2000). This syndrome may result in older adults gaining fat mass without an accommodating growth in muscle mass and strength to overcome the gravitational burden of an increased body mass. Depending on the definition, approximately 5-10 percent of older adults would be defined as having sarcopenic obesity today which is equivalent to 40-80 million globally (Stenholm et al., 2008). The proposed causes of sarcopenic obesity are similar to the individual syndromes themselves, but narrow in on physical inactivity and the immobilization of sedentary behaviors as key culprits. Moderate-to-vigorous intensity physical activity has been identified as a significant modifiable risk factor for obesity and PA, with relatively new research highlighting the importance of LPA and SB. This will be described in the plasticity of these physical changes and body composition in the following section.

Plasticity of Physical Function

Frailty has been previously identified as an inescapable physical trait where a tipping point was reached between living to dying. But observations in both the biological and social sciences have shown that individuals can frequently transition into and out of these frailty states.

In one of the first studies observing the progression of frailty in the Women's Health and Aging Study (WHAS) II cohort, it was identified that transitions across states occurred much more frequently than previously postulated. Additionally, most frequent transitions over 18-month periods occurred in the direction of greater frailty, but approximately one-third of all transitions were toward less frail states (Gill, 2010). This observation showed that transitions can occur in a healthier direction and that not all individuals were seemingly doomed to a fast-tracked path to an inescapable end-of-life state.

It was later identified in the same WHAS cohort that progression through the frailty states has inter-individual variation with most transitioning slowly into adjacent frailty states and approximately one-third completely skipping pre-frailty and enter a frail diagnosis in an 18-month period. This suggests that a slippery slope does exist with some individuals in a non-frail state and that some may be at greater risk than others. More sensitive measures of physical capacity and risky behaviors may be needed to identify these vulnerable non-frail populations.

Key behaviors that have been linked as significant modifiable factors for physical traits and functioning include PA and SB. Both PA and SB have been identified as mutually independent predictors of physical limitations and risk of frailty among older adults (Gennuso et al., 2013; Lee et al., 2015). Population-based investigations have identified that older adults with greater aerobic PA participation experienced a higher functional status in older age (Paterson and Warburton, 2012). Additionally, PA participation decreases and sedentary behavior increases progressively with age presenting a possible modifiable risk factor for physical function in old age (Matthews et al., 2008).

Using a nationally-representative cohort from the National Health and Nutrition Examination Survey data, Gennuso and colleagues (2013), identified a significant positive trend in self-reported physical limitation among increased quartiles of time spent in sedentary behaviors and a significant 60 percent reduction in odds risk of reporting a physical limitation when meeting the Physical Activity Guidelines for Older Adults. Among the Health, Aging and Body Composition cohort (ABC), those who regularly engaged in PA at baseline were 45 percent less likely to develop physical limitations resulting in frailty following a five year period when compared to those who were physically inactive at baseline (Peterson et al., 2009).

In an observed "chicken or the egg" scenario, where physical inactivity leads to frailty or frailty leads to physical inactivity with aging, it appears that both contribute significantly to each other creating a vicious cycle. With an inevitable, age-related decline in muscle mass and functional abilities combined with an environment that promotes inactivity and sitting, the least active seem to exacerbate the progressive muscle loss presenting the most vulnerable population to become frail. Therefore, these individuals may have a physiological ceiling that is not being met and can still be attained, allowing for a reversal in a premature frailty status. Thus, it is postulated that the introduction of PA and avoidance of sedentary behavior may be able to prevent frailty in at risk populations.

Summary of Physical Function and Aging

Compared to previous cohorts of older adults, the age of which physical disability and lost independence is apparent occurs later in life. Nonetheless, over the next 25 years the proportion of older adults reaching advanced age (85+ years) is expected to triple with these years experiencing the greatest risk of comorbidity and disability prevalence. While age-related muscle loss is a common final pathway to mortality, there is inter-individual variability in the trajectories and transitions of frailty depending upon a complex interaction of genetics, environment, and behavioral factors. Although research involving age-related muscle loss, functional limitations, and frailty are relatively new, PA and SB have been identified as significant contributors of the physical traits related to functional capacity. Physical activity and SB as key modifiable determinants of physical functioning will be outlined in the remaining sections of this literature review.

Epidemiology of Physical Activity and Sedentary Behavior in Older Adults

Introduction

The improved treatment and management of comorbidities continually adds minor changes to life expectancy, yet underlying physiological decline leading to mobility loss and functional impairments remain. Without a cure-all pill for aging, the best medical advice to reduce mobility loss and promote healthy aging is PA participation. Physical activity, or bouts of exercise in particular, has been proven as a strong preventative and therapeutic option for morbidity and mortality (US Department of Health and Human Services, 2008). The purpose of this section is to highlight the current understanding of the associations between PA and SB with functional health.

The early work performed by Professors Jerry Morris and Ralph Paffenbarger in the latter half of the 20th century helped to establish a foundation for understanding the association between PA and public health. Physical activity epidemiology is the study of the relationships linking PA, or inactivity, to disease and the distribution of recognized determinants in a population (Dishman, Heath, & Lee, 2012 pg. xi). Likewise, the epidemiology of SB features the same level of inquiry but with the distinction of focusing on sitting behaviors rather than PA participation. Physical activity epidemiology has a longer and more solidified history of scientific inquiry linking PA or exercise to fitness, health, and well-being dating back to the mid-20th century, while the formal definition and understanding of SB as a discrete contributor to health and physical function has only occurred in the most recent decade. It is important to understand the distinction between exercise, PA, and SB. Physical activity is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (Casperson, Powell, and Christenson, 1985) and can occur in domains like occupation, leisure, travel, and household. Physical activity can occur at different intensities which directly affect the rate of energy expenditure (kcal/kg/hr or MET) along a continuum. Different classifications of PA are defined by the range of energy expenditure that the underlying PA demands: SB (≤1.5 MET), light-intensity PA (LPA, 1.5-2.9 MET), moderate-intensity PA (MPA, 3.0-5.9 MET), and vigorous-intensity PA (VPA, 6.0+ MET). Therefore, it is important to acknowledge that PA and exercise are not synonymous. Exercise is identified as a “subset of physical activity that is planned, structured, repetitive and has a final or intermediate objective for the improvement or maintenance of physical fitness” (Casperson, Powell, and Christenson, 1985). As exercise is often identified as intentional and planned, bouts of MPA and VPA lasting longer than 10 min are typically used to categorize this PA towards exercise rather than incidental PA. Exercise can then be broken into different modalities developed to affect specific attributes of physical fitness, including cardiorespiratory fitness, muscular strength and endurance, flexibility, body composition, and skill-related components. “Physically inactive” is based on a dichotomy of either meeting or not meeting a specific cut-point of 150 minutes of MPA or 75 minutes of VPA per week (US Department of Health and Human Services, 2008). Furthermore, groups can be stratified by level of being "physically active" to compare absolute time spent in PA or proportion of a subgroup that participates in PA [i.e., among older and younger adults that do not meet the PA guidelines (physically inactive), older adults were less physically active with than younger adults].

While sedentariness and physically inactive have been previously used synonymously in the PA literature, a more formal definition of SB was provided due to the discrete physiological nature of prolonged sitting a half-decade ago. Sedentary behavior is identified as a seated or lying position with energy expenditure ≤1.5 metabolic equivalents of task (MET) (Sedentary Behavior Research Network, 2012). Therefore, one that has not met the 150 minutes per week of moderate-to-vigorous aerobic activities is to be identified as physically inactive, not sedentary. Current nomenclature does not identify these individuals as a "sedentary"-type because there is not a current cut-point to determine a specific value of sitting time as of being detrimental to health. Just that more is worse and how the time is accumulated may be more important. For example, accumulating bouts of SB lasting 20 minutes or longer with less breaks in SB throughout the day has been linked to poorer health outcomes than overall SB time (Healy et al., 2011). Therefore, just as PA can be characterized by the FIIT principle (frequency, intensity, time [duration], and type), key SB characteristics include the SITT principle including **S**edentary behavior frequency, number of **I**nterruptions, **T**ime [duration], and **T**ype (Tremblay et al., 2010). Generally, reported SB outcomes will include total time accumulated, number of prolonged SB bouts, interruptions in SB, and number of sit-to-stand transitions.

To better understand the rationale for developing an evidence-based intervention that targets improved physical function through the manipulation of PA and SB, the following section will include a review of the current methods of PA and SB measurement, age-related trends in

PA and SB based on population statistics, evidence linking PA and SB to functional health, and determinants of PA and SB in aging.

Measurement of Physical Activity and Sedentary Behavior

The distinction and categorization of different characteristics of PA and SB have become more pronounced and discrete in the past half-decade. For example, most initial investigations on the impact of PA often relied on the reporting of regular exercise, but this limited the information that could be obtained about the types and levels of PA in the remaining 97+ percent of waking hours. Scientific inquiry has teased apart the descriptive characteristics of PA and SB, fueling the development of new technology better able to distinguish each characteristic and their distinct physiological and health-related implications. In particular, the development of more descriptive questionnaires including the frequency, time, duration, and type of PA in different domains to inclusion of wearable devices to predict energy expenditure have led to a more encompassing, accurate, and precise collection of PA data.

Similar to the discussion on physical function, self-reported PA has its benefits of being relatively inexpensive and practical in large-population based studies, but come at a cost of accuracy when compared to direct and more objective measures of PA. Prince and colleagues (2008) identified that self-reported measures that were collected through questionnaires, surveys, logs/diaries, and interviews were low-to-moderately correlated with discrepancies higher and lower than direct measures. In contrast, doubly-labeled water remains the gold standard method for assessing total energy expenditure, but is expensive, less practical to administer, less acceptable for the participant, and lacks qualitative depth compared to self-report measures. The following section will summarize methods of assessing PA and SB with considerations of validity, reliability, and sensitivity. Measures of PA and SB lie along a continuum that balances ease of use with precision, where room calorimetry carries the greatest precision with most limited ease of use on one end of the continuum and self-report surveys with the least precision and greatest ease of use on the other end.

Self-report. Questionnaires are the most common method of assessment for PA that rely on participants' recall ability to provide various information regarding previous, recent, or habitual behaviors (Castillo-Retamal and Hinckson, 2011). Obtained information can range from a simple "yes" or "no" response for exercise participation to more descriptive information. PA questionnaires can measure different variables of PA including frequency, duration, intensity, and type of activity performed, they differ in how the data is reported (MET-hr/wk: indicator of intensity and duration of PA per week, PA scores, or energy expenditure), and in the period of interest (lifetime, habitual, or past year, month, week, or day). Further, targeted population is important when developing and applying PA questionnaires with contexts of time spent in PA differing by age, gender, SES, and/or nationality.

In a review of the seven most commonly used and studied self-report PA questionnaires, there was moderate to strong reliability and validity across these instruments in a generic non-age specific reporting (Sylvia et al., 2014). Self-report instruments reviewed included the Modifiable Activity Questionnaire (MAQ), Previous Week Modifiable Activity Questionnaire (PWMAQ), International Physical Activity Questionnaire (IPAQ), Recent Physical Activity Questionnaire (RPAQ), Previous Day Physical Activity Recall (PDPAR), and 7-day Physical Activity Recall (PAR). These self-report instruments provide a variety of information regarding time period of interest, activity categories included, and output with determination of one over the other largely dependent on the research question. For example, the IPAQ is primarily concerned with the duration and frequency of general activities like MPA, VPA, walking, and sitting in the past week. Meanwhile, the PDPAR is concerned with the specific activities of that took place in the previous day during 30 minute intervals, including eating, sleeping, bathing, transport, occupational, recreational, and exercise activities. Thus, questionnaires are designed with a dependency on recall, limiting more descriptive information to recent days and more general activities based on lifetime periods. However, the previously mentioned questionnaires have largely been developed based on younger populations aged 18-65 years and only the PAR (Dubbert et al., 2004), PDPAR (Westerterp et al., 1994), and IPAQ (Grimm et al., 2012) have been validated in older adult populations.

In the efforts to test the validity of these generic instruments in older adult populations there is concern for a lack of sensitivity to this particular population. A comparison of the IPAQ and body-worn accelerometers identified significant low-to-moderate correlations between walking, sitting, and total PA (Grimm, Swartz, Hart, Miller, & Strath, 2012). There was a significant underestimation of time spent sitting and overestimation of all PA intensities with a 40-46% agreement between the instruments for meeting the PA recommendations. Therefore the authors concluded that the IPAQ may not be suitable for measuring PA in smaller sample studies, but may be suitable for generalizing time spent in these activities in larger populations-based studies.

While these generic self-report instruments have continued to be used in older adult populations, there remained concern of their ability to accurately capture the PA of older adults. This led to the development and evaluation of PA questionnaires and surveys specific activities typically performed in a 60+ year old population. DiPietro, Casperson, Ostfeld, & Nadel (1993) evaluated the Yale Physical Activity Scale (YPAS) which was designed to target those aged 60-

86 years. Between 1987 and 1989, Yale University and the Centers for Disease Control investigated methods to assess PA patterns of those 60+ years old and living in Connecticut. Two-week reliability was found to be between 0.42 and 0.65 ($p = 0.0002$ and 0.0001, respectively) among 76 healthy older adult volunteers and validity indicated by significant correlations between of the activity dimensions summary index with weekly energy expenditure ($r = -0.47$, $p = 0.01$) and VO2max ($r = 0.58$, $p = 0.004$). While the PASE was found to be a reliable and valid measure of moderate and vigorous PA, its accuracy in assessing PA on the lower end of the PA continuum was not established. Similarly, Washburn, Jette, & Stewart (1993) evaluated the Physical Activity Scale for the Elderly (PASE) which was developed to describe leisure, household, and occupational activities of older adults in the past 7 days. The PASE has been identified as having high acceptable test-retest reliability (Washburn et al., 1993) and moderate construct validity among community-dwelling older adults when compared accelerometer counts (Dinger et al., 2004).

The Community Health Activity Model Program for Seniors PA self-report questionnaire (CHAMPS) was developed to keep in mind the various types and intensities of activities specific to older adults. This was based off the more recent evidence that the whole continuum of PA may be linked to health and wellness in later years (Stewart et al., 2001). An evaluation of the CHAMPS, there was moderate-to-high test-retest reliability (ICC: 0.56-0.70) and moderate correlations with total PA, high-LPA, and MVPA when compared to accelerometers (Hekler et al., 2012). Correlations with low-LPA and SB were significant, but lower, indicating a need for more sensitive instruments for these areas of the PA continuum.

Concerns with self-reporting along the lower PA continuum are not immune to older adults, but have been experienced in non-age specific questionnaires as well. Prince and colleagues (2008) reported on the various types of measurement methods or survey employed, the level of PA measured, and the gender of the participants. Interestingly, as the level of intensity increased (light, moderate, vigorous) the mean percent differences between self-report and objective measurement increased. This divergence often results in an overestimation of high PA levels and an underestimation of activities in the SB and LPA range. This was evident in the large, nationally representative NHANES sample where the authors hypothesized a misclassification of SB and LPA by respondents or an underestimation of accelerometers (Troiano et al., 2008). Besson and colleagues (2010) suggested that PA questionnaire's lack of sensitivity to lower intensity activities which may be due to recall error (Besson et al., 2010). Social desirability may play a role in the overestimation of MVPA and underestimation of SB and LPA (Prince et al., 2008). Collectively, these errors may contribute to a less accurate means of measuring habitual energy expenditure when compared to more direct methods (Shephard, 2003).

Considering that the formal definition of SB was not provided until 2012, discrepancies between self-reporting of activities spent in the lower end of the PA continuum and objective reporting is not surprising. Prior to this, several proxy measures of SB have been used in the review of previous literature. For instance, a systematic review of SB literature in 2013 provided self-reported sitting, TV time, computer time, screen time, and accelerometry are in general reliable and valid forms of measurement (Harvey, Chastin, & Skelton, 2013). But the delineation of SB and LPA was more of a grey area until public health experts and researchers decided on definition that incorporated both biopsychosocial and energy expenditure related components.

Self-reported overall SB time can be provided through a single item estimation or by summarizing a list of various domain-specific behaviors throughout the day. Similar to PA, SB questionnaires are inexpensive, practical, and acceptable with participants, but susceptible to reporting errors due to external factors and systematic errors from criterion measures. Healy and colleagues (2011) provide a tabulated summary of test-retest reliability and criterion validity for self-report instruments for SB time. In summary, Healy and colleagues (2011) identified that a majority of self-report SB instruments having good test-retest reliability with stronger reliability among SB performed on a regular basis and for prolonged durations. Regarding validation of these questionnaires, the criterion measure largely employed was the use of accelerometry and behavioral logs with higher correlations for specific behaviors in various domains than for overall sitting time.

The systematic measurement error from self-report questionnaires can lead to an underestimation of the relationship between PA and SB with health outcomes. Grimm and colleagues (2012) identified an underestimation of SB and overestimation of MVPA when comparing the IPAQ (to accelerometer-derived measurement in older adults Specifically, the IPAQ underestimated SB by 262 minutes (13%) by 262 minutes and overestimated moderate lifestyle by 14.7 minutes, moderate walking by 26.5 minutes, and VPA by 43.1 minutes. These findings are consistent with those of Celis-Morales et al. (2012) and, interestingly, the associations of SB and MVPA with certain cardiometabolic risk factors only remained significant when accelerometer-derived measures were used, as opposed to self-report. This suggests that the use of questionnaires may underestimate or fail to detect potential relationships between SB or MVPA and cardiometabolic risk factors. A systematic review by Harvey and colleagues (2015) identified that most large health surveys that utilize self-report as a method of measurement for SB likely underestimate time spent sitting by nearly two-fold in older adults. Furthermore, Kowalski et al. (2012) suggest that older adults are more likely to undertake LPA, but are less likely to recall it.

With a variety of self-report PA questionnaires instruments available, it is important to remember that although several share a similar purpose, not all have been validated against the same criterion, construct, or content measures. This is especially important when determining the intended outcomes and the population of interest. Eckert and Lange (2015) used the ICF as a standard reference to evaluate the content validity of 18 questionnaires and their items specifically targeting the PA of older adults. There was wide variability in the collection of activities within each the four recommended domains of PA (household, leisure, travel, and occupation) with only four of the 18 self-report instruments including all four domains and seven not including SB. Further, the authors found the inadequate and inconsistent reporting of SB and LPA in older adults troubling considering that times spent these areas contribute to the greatest amount of daily activities. Until PA and SB questionnaires have gained sufficient sensitivity to accurately describe the entire 24-hour activity portrait, the use of more objective measures should be included to aid data collection.

Objective Assessment. The criterion measure for classifying PA and SB is direct observation. During direct observation, behaviors are monitored and recorded by an independent observer typically within a domain (home, leisure, occupation, travel) and is particularly useful among populations that have difficulty in recalling information. In certain older adult populations, the ability to recall PA and SB may be compromised and direct observation can be a means to overcome this. Following adequate training, direct observation can be a reliable and valid method of assessing PA or SB with the benefits of adding context and details about the physical and social environments to the activities. However, direct observation is expensive, labor-intensive, does not capture objective measurement of energy expenditure, and may suffer from reactivity to the observer (Healy et al., 2011).

Pedometers are small, hip-worn devices designed to count the number of steps performed based on the force generated along a single axis. Tudor-Locke and colleagues (2002) identified a strong correlation between pedometer-derived step counts with uniaxial accelerometers (r=0.86) and direct observations (r=0.82). However, strength of associations with energy expenditure (r=0.68) was reduced, as pedometers are not discriminatory between the intensity of the steps. For example, step counts from walking, running, and taking the stairs would be assumed as requiring the same energy expenditure although more objective measurements through indirect calorimetry identify these activities are distinct (Ainsworth et al., 1993).

The generic recommendation for all to achieve 10,000 steps per day was provided by the *2007 President's Council on Physical Fitness and Sports* based on the *1996 US Surgeon General's* recommendation to perform at least 30 minutes per day of PA (US Department of Health and Human Services, 1996). Miller and Brown (2004) identified that among working individuals that average at least 150 minutes per week of MVPA averaged approximately 9,550 steps per day.

The lower cost and smaller size of accelerometer devices have allowed for accelerometers to be increasingly practical and acceptable in large scale PA research since 1981 (Ward et al., 2005). Accelerometers typically caption bodily motion through a piezoelectric element that sends a voltage signal to be recorded when bent in proportion to accelerations detected (Chen and Bassett, 2005), thus converting mechanical motion into electrical information. The incorporation of an internal clock, increased storage memory, extended battery life, and bandpass filters have allowed researchers to more objectively detect and measure various intensities of PA over extended periods of time which may better reflect habitual activities. There is not a current unified standard for how devices collect, process, and filter the raw data obtained, which impedes the ability to compare counts across accelerometer devices. However, common processing and reporting includes the use of accelerometer counts, or units, that are typically accumulated within a 60-second time sampling interval, or epoch. In order to interpret accelerometer output, certain cut-points or counts per minute (cpm) thresholds have been developed to accurately categorize SB (<100 cpm), LPA (100-1951 cpm), MPA (1952-5724 cpm), and VPA (≥5725 cpm) (Freedson et al., 1998).

The study sample must be considered when applying a cut point for accelerometers to estimate the level of PA performed. Several cut points have been applied to PA monitoring, which include both ambulatory and lifestyle validation studies and the determination of PA prevalence can vary widely depending on the type of cut-point used. For example, applying ambulatory and lifestyle derived cut-points to the same 2003-2006 NHANES data identified a median of 12% and 77% of adults met the 2008 PA Guidelines, respectively (Watson et al., 2014).

Lifestyle PA cut-points are in nature more comprehensive, taking into account body movements that involve less vertical accelerations but include large muscular contractions to perform activities like gardening, washing dishes, raking, mowing, mopping, etc. Thus, lifestyle movement patterns provide lower cut-points for the same amount of energy expended determined through indirect calorimetry, a criterion measure (Bassett et al., 2000; Matthews, 2005; Swartz et al., 2000). Regardless of cut points used, patterns of PA prevalence are generally consistent among 60+ year olds in the NHANES data set (Evenson et al., 2012).

Typical monitoring periods often include either 24-hour or waking hour wear time periods across approximately seven days and valid wear time can be assessed through the combination of algorithms (Choi et al., 2011) and wear logs. Although participants with at least 3-5 days of valid wear time are typically included in analysis, suggested monitoring periods vary by age with older adults recommended to capture at least 5 (Hart et al., 2011).

Accelerometers originally included only a single axis (vertical), but now can include three axes (vertical, horizontal, frontal), the use of gyroscopes to detect body position, wireless internet and GPA to ping location, heart rate monitors to better asses energy expenditure, and inclinometers to asses body position. There are different manufacturers of accelerometers, or postural monitors available. One such device, the ActivPal, uses inclination output is useful at distinguishing between seated or lying postures with standing postures, which is particularly important given the current definition of a SB (R^2=0.94 with direct observation) (Kozey-Keadle et al., 2011). Therefore, activity monitors that do not capture changes in posture may risk misclassification of low-movement standing activities or standing breaks as continued SB. This is concerning, considering much of the health effects of SB have been based on the assumption that low activity counts for standing and sitting are equal, which is counter to what acute responses to skeletal muscle and glucose metabolism suggest (Tikkanen et al., 2013; Henson et al., 2016). In one comparison study, the Actigraph GT3X+ on average recorded less SB time than the ActivPal with a relatively high correlation (rho=0.76) in the general population (Matthews et al., 2008).

Within objective measurements that use accelerometry, a majority of studies rely on lack of activity counts as a proxy measure of SB. Specifically, a traditional accelerometer cut-point of 100 counts per minute traditionally is used to identify a period of low energy expenditure in adults (Healy et al., 2007; Ekelund et al., 2007; Matthews et al., 2008). Therefore, the accelerometer used in several of these population-based studies is unable to identify whether the individuals are actually lying, seated, or standing but still. Efforts to overcome this include the use of the ActivPal device which uses a tri-axial accelerometer placed on the mid-thigh, acting as an accelerometer to detect activity counts and an inclinometer to distinguish between seated and standing postures. Kozey-Keadle and colleagues (2011) identified that the ActivPal device was more precise and sensitive to the detection of sitting time compared to a hip-worn accelerometer. In addition, this validation study identified that a hip-worn accelerometer cut-point of 150 counts per minute may be more appropriate in identifying SB. However, these cut-points were used in middle-aged adults without empirical evidence to validate these cut-points for SB in older adults (Schrack et al., 2016).

In summary, several co-existing and dynamic factors come into consideration when determining an instrument for assessing PA and SB. This can include the availability of resources, cost of the instrument, feasibility and practicality, and outcomes of interest. Strath and colleagues (2012) developed a decision matrix to assist the researcher in selecting a device based on the given conditions. However, if choosing to assess PA with a more objective method like accelerometry, it should not be assumed that this is an omnibus measure and PA questionnaires should be used to supplement the body-worn devices with contextual information to provide a complete portrait of daily and habitual activities.

Prevalence and Trends of Physical Activity and Sedentary Behavior

Trends in PA and SB have evolved over the course of history with cultures progressing from hunters and gatherers to agricultural societies to automation in the industrial age and the computerized digital technology of today. This has transformed how we move in our physical environment during times in the home, occupation, travel, and leisure. Much of what we do in our daily lives is aided by convenient technologies that reduce PA-related energy expenditure. For example, the invention of the remote control, elevator, automobile, and digital library catalogs are convenient, but developed to reduce the burden of human movement and time to copmletion. It is estimated that occupation-related PA energy expenditure in the US has decreased by approximately 142 calories per day since 1960 (Church et al., 2011). These changes have progressed annually and coincide with growing trends of an increasingly overweight and obese population. These deficits in PA-related energy expenditure can be translated to other domains as leisure-time is increasingly including screen-based activities and suburban expansion is increasing the dependence on passive, automated transport. Independent of these historical changes in PA, clearly defined age-related trends in PA and SB are present.

Physical activity and aging. Both self-report and accelerometer data of population-representative monitoring have indicated that older adults accumulate the least amount of MVPA. Reporting from the 2003-2004 NHANES cohort indicated that older adult women and men aged 60-69 years accumulate between 12 to 17 min/day of total MVPA and those 70+ years accumulate between 5 to 9 min/day of total MVPA (Troiano et al., 2008). These data were analyzed using an MPA cut-point of 2020 cpm, which is slightly higher than the 1952 cpm cut-point for MPA suggested by Freedson et al. (1998) which may slightly underestimate total time in MVPA. Regardless of cpm cut-point used, Davis and colleagues (2007) identified that older adults accumulate a significantly lower cpm average than younger adults (37 percent, $p<0.001$).

Also, less than half of older adults aged 70+ years accumulated any time in MVPA spent in bouts lasting longer than 10 minutes (Davis et al., 2007) and it is estimated that less than three percent of the older adult population likely fulfills the PA guidelines when applying accumulated 10 minute bouts of MVPA (Jefferis et al., 2015).

Kozey-Keadle and colleagues (2016) used three nationally representative surveys to assess the adherence to the PA guidelines by older adults and changes over the time these surveys have been administered. The surveys included the National Health and Nutrition Examination Survey (NHANES), National Health Information Survey (NHIS), and Behavioral Risk Factor Surveillance System (BRFSS) with self-report of ‘no leisure time activity’, ‘insufficiently active’, or ‘met guidelines’. The PA guidelines were based on the US Surgeon General’s recommendation of 150 min/week of MPA, 75 min/week of VPA, or a mixture of the two (Physical Activity Guidelines Advisory Committee, 2008). In summary, males on average were more active, there was a significant negative trend for meeting the PA guidelines with age, and the identification of those that met the guidelines varied by survey method. Self-report of meeting the guidelines were between 27.3% and 44.3% and those reporting ‘no leisure time activity’ ranged from 36.1% to 60.9%. Only between 16.7% and 21.6% met the strength training guidelines with a negative trend for age. Between 1998 and 2013, there was an increase in older adults that reported meeting the guidelines from 25.7% to 35.2% and ‘no leisure time activity’ decreased from 55.9% to 43%. Lastly, young older adults (65-74 years) were twice as likely as those aged 85+ to meet the PA guidelines.

Within older populations, there is large heterogeneity in the functional ability and mobility. It is estimated that those currently experiencing functional limitations due to chronic illness may be up to 50 percent less active than healthy controls (Strath et al., 2012).

Accelerometer-derived observations of PA have been performed on those with neurological dysfunction (Hale, Pal, & Becker, 2008), kidney disease (Johansen et al., 2008), multiple sclerosis (Motl, Snook, & Agiovlasitis, 2011), knee osteoarthritis (Song et al., 2010), and Parkinson's disease (Nero et al., 2015). However, the use of accelerometer derived cut-points from healthy samples are often applied to these functionally impaired populations with a variety of devices, placements, and raw data analysis without consistency from study to study.

Sedentary behavior and aging. Population-representative observations have consistently identified older adults as a segment that accumulates the greatest amount of SB. According to both self-report and objective measurements, older adults spend approximately 65-80% of their waking hours in SB, or up to and beyond 9 hours per day (Harvey, Chastin, & Skelton, 2013; Harvey, Chastin & Skelton, 2015; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Matthews et al, 2008, Shiroma et al 2013).

In particular, accelerometer-derived measures of SB using the 2003-2004 NHANES cohort identified a significant linear trend for age and SB ($p<0.001$) with each increasing decade past older adolescents related to an increase in overall time spent in SB (Matthews et al., 2008). Older adults aged 60-69 years spent approximately 8.4 hours/day, or 60% of their day, in SB with those aged 70-85 spending 9.3 hours/day, or 67% of their day in SB. On average, older adult men accumulated more SB time than women and Mexican American adults were les sedentary than other US adult groups. These estimates were confirmed later by Healy and colleagues (2011) using NHANES data from 2003-2006 and incorporating the use of self-reported SB behaviors like sitting most of the day, high screen time (≥ 3 hours), TV time (≥ 3 hours), and computer use (≥ 1 hour). There were significant gender differences within domain-specific measures with men more likely to report high TV time, computer use, and screen time.

After the age of 30, mean accelerometer-derived SB time increased with age, along with prevalence for self-reporting for sitting most of the day, high TV time, and high screen time. Younger adults aged 20-59 average 8.3 hours/day in SB and older adults aged 60+ averaging 9.35 hours/day in SB.

A systematic review by Harvey, Chastin, & Skelton (2013) included 23 studies with 372,550 individuals across seven different countries and incorporating the use of various self-reported proxy measures of SB and one accelerometry-derived measurement. Self-report data identified that approximately 60 percent of older adults from international cohorts reported sitting for more than 4 hours per day and accelerometer-derived data indicated that 67% of older adults sit more than 8.5 h during waking hours of the day. Over half of the older adults in this meta-analysis reported watching more than 3 hours of TV per day and 15 percent watched more than 4 hours of TV per day with TV time increasing with age. Also, there was a significant increase in self-reported sitting time of greater than 4 hours between the 65-74 year old age group and the 75+ year age group. Thus, this is not a public health issue isolated within the US, but among most first world countries.

Harvey and colleagues (2015) provided another systematic review of SB in older adults using international cohorts to identify 5.2-6.7 hours of self-reported SB time (weighted average of 5.3 hours) and 8.5-10.7 hours (weighted average of 9.4 hours) of objectively measured SB time in those aged 60+ years. According to self-report and objective measures, men on average sit more (30 minutes and 9 minutes, respectively). On average, SB increased with age until the age of 90 years, which may be due to the limited data within this age group, and older adults reported greater SB time than younger adults in all domains (TV, reading, occupational, etc) with an exception to computer use and total screen time. The lower SB in the 90+ year age group was hypothesized to be due to individuals that reach this age successfully by being healthier or more fit, or that the self-report within this group may not be reliable.

The driving force for increased SB with age may be due to several factors, but a key hypothesis includes occupational status. Godfrey and colleagues (2014) examined the relationship between retired (n=66) and non-retired (n=32) status with SB and PA in 98 community dwelling older adults. In agreement with other studies, time spent in SB increased with age and ambulatory activity reduced with age. However, retirement status was linked to reduced time spent in SB, reduced bouts of sitting lasting greater than 55 minutes, and increased ambulatory activity. Lastly, only 21% of older adults achieved the 150 minutes per week recommendation for MVPA with no difference between retirement statuses. This contradicts the stereotype that retirement status is linked to increased SB. However, the small sample in this study were from higher socioeconomic status and employment was not physically demanding prior to retirement and in the non-retired group.

Cross-sectional data have consistently suggested that PA declines with age with concomitant increases in SB, but longitudinal studies are necessary to confirm these results. Jefferis and colleagues (2015) used a population-based cohort of men aged 70-90 years (n=1419) from the United Kingdom with accelerometer-derived SB and PA to track changes in activity across a two-year span. At baseline, the men spent 72.5 percent of their waking hours in SB, 23.1 percent in LPA, and 4 percent in MVPA. There was an annual 7 percent reduction in steps/day, while SB increased by 1.1 percent, LPA decreased by 0.7 percent, and MVPA decreased by 0.4 percent. Also, the older adult men were nearly twice as likely to stop meeting the PA guidelines (8.2 percent) than to begin meeting the PA guidelines (4.9 percent) after two years. Increases in SB were more likely to come from LPA than MVPA; however, the 0.4 percent reduction in

MVPA from total wear time represents an annual 10 percent reduction in time spent in MVPA. Meanwhile, the 0.7 percent of reduced LPA represents a 3 percent reduction in LPA time. The authors propose that the reductions in time spent in higher intensities may be due to declines in physical functioning rather than volitional PA and that strategies should be developed to target increases in LPA to replace the shares of MVPA being replaced by SB.

Determinants of Physical Activity and Sedentary Behavior

Today's society is bombarded with technologies that continuously and exceedingly enable a sitting posture or reduced energy expenditure during work, leisure, and travel. Inventions like the Lazy Boy recliner, television with remote control, computers, handheld devices, and automobiles all provide a convenience while reducing energy expenditure during leisure, work, and travel. Rather than standing up and reviewing the library catalogs and walking up four flights of stairs to pull a book reference from a shelf, one could attend the library website from their bedroom, search the intended book reference, and receive a digital copy. While the difference in energy expenditure from this single example may not alone influence changes in body composition, physiological function, health, or well-being, the accumulated daily effects appear to. Because technology and automation will continue to advance, it is important to identify and introduce opportunities to maintain PA. By 2035, it is estimated that the current 20 percent reduction in work-related PA is going to reach 35 percent (Ng & Popkin, 2012).

Better understanding of particular SBs and SB settings are believed to provide a stronger case for developing effective interventions to this unhealthy behavior. It is through this understanding that both distinct determinants of SB may be at play, depending on the individual and/or their physical environment. Physical activity research has identified that factors related to

PA behaviors should not be identified generically, because specific settings can influence certain behaviors. For example, why are social activities for older adults predominantly spent sitting? Wicker (1979) suggests that individuals are a part of a larger behavior-setting system with default behaviors set as the norms which naturally restrict the adoption of other behaviors in that setting and sometimes discouraging or prohibiting some behaviors or promoting other behaviors may be necessary. Maybe, we have come to a point where sitting while watching TV is being discouraged and/or exercising while watching TV should be promoted.

Human behaviors are complex and the current approaches to understanding it include theoretical frameworks using proximal and distal interactions within an ecological model (Owen et al., 2011). The ecological model includes multiple levels of influence on a behavior including individual, social, community, environmental, and policy factors (Sallis et al., 2008). By focusing on the domains (leisure/household/occupation/transportation) where SB occurs and how the contextual factors (environmental/social/organizational) contribute as determinants of SB, we will begin to better understand how individual-level influences like preferences, barriers, and enjoyment and proximal-social relationships like home and work contribute to sustained behaviors and intended change (Owen et al., 2011).

Chastin and colleagues (2015) incorporated the ecological model as a theoretical framework to categorize and summarize potential determinants of SB among older adults in a systematic review. Significant individual determinants for SB were age, employment /retirement status, obesity, and health status. Specifically, age was positively associated with increased SB time with older adults spending approximately 1 hr/day more in SB than adults (Hamrik et al., 2014) and an observed 5 percent increase in total daily SB time per year after the age of 65 (Shiroma et al., 2013). Gender difference was inconsistent across studies, which may be due to other complex interactions including cultural norms, pre-retirement job classification, and gender-specific TV viewing. Males that had labor-intensive occupations before retirement often experienced the greatest increase in retirement TV viewing as white-collar workers in retirement increased TV time by 2.6 hours and blue-collar workers by 3.9 hours (Barnett et al., 2014). In general, retirement status presented a significant negative association with SB time with those not working at least 35 hours per week increasing the odd ratio of TV watching two-fold (Kikuchi et al., 2013). While one study did cite lower levels of SB time in retired compared to employed older adults, this was attributed to longer SB durations in those employed which may be related to employment type and/or occupational-related fatigue in the home (Godfrey et al., 2014). Further, volunteering during retirement may attribute to these differences with volunteer duties linked to a 15 min per day decrease in SB time (van Cauwenberg et al., 2014), suggesting that maintained activities or social roles in retirement may be protective from SB. The surge of new questions from the quantitative analysis of SB highlights the demand for future research to incorporate qualitative methods.

Several studies have identified a significant positive association between SB and obesity (Chastin et al., 2015). Also reported is a significant inverse relationship between self-rated psychological and functional health with SB. Moreover, it was identified that fatigue during standing and functional limitations are important determinants for sitting (Chastin et al., 2012, Chastin et al., 2014). Interestingly, mid-life obesity and cardiovascular health were significantly associated with older adult SB time which leads to a hypothesis that these comorbidities may be additional determinants of SB, rather than isolated outcomes of SB (Van der Berg et al., 2014).

Key environmental determinants for SB are mode of transport, housing type, cultural opportunities, neighborhood safety, and availability of seated areas. Living alone was linked to a

26% increased odds ratio of TV time compared to a shared living space among 1655 older Japanese men and women (Kikuchi et al., 2013). Mixed neighborhoods of older and younger adults appeared to be protective of SB time (van Cauwenberg et al., 2014). Those in rural Japan had a 48% higher odds ratio of TV watching time compared to those living in urban environments (Kikuchi et al., 2013), while a Belgian cohort of 51,000 identified a 10 min per day increase in TV time for those living in urban environments (van Cauwenberg et al., 2014). These conflicting findings hint toward cultural or region-specific environmental influences with further research needed to clarify these discrepancies. In other reports, cultural facilities and green spaces were protective against SB time and perceptions of unsafe neighborhoods were related to increased TV viewing (Chastin et al., 2015).

In a qualitative assessment for key interpersonal and environmental reasons of sitting among nine community-dwelling older women included societal and environmental stereotypes that older adults should sit often, pressures from inner social circles to sit more, and a lack of environmental stimuli or active-promoting facilities. A key theme among participants was the lack of resting places along walkways. Without a presence of staggered resting places, the older women felt inclined to sit inside out of fear of being too tired or embarrassed for an inability to walk continuously and being “caught short”.

In an effort to identify when and where to target SB interventions, Leask and colleagues (2015) detailed specific charactersitics of SB, including the ‘what’, ‘where’, ‘why’, ‘when’ and ‘with whom’ of SB in older adults. A total of 36 participants with an average age of 73 years wore an activPAL monitor and a time-lapse camera. Sedentary behavior was determined by the activPAL device and the domain/context was coded by the time-lapse pictures using the Sedentary Behaviour International Taxonomy classification system. Household, leisure, and transport were the primary domains where SB was to occur in the older adults sampled with 70.1% of daily SB occurring in the home. Leisure time was primarily responsible for sedentary bouts consisting of 49.2% of SB time and a majority of SB took place in the homes in the afternoons while solitary.

Regarding screen-time in older adults, a systematic review identified that 53 percent of the older adults reported sitting in front of a screen for greater than 4 hours per day. A majority of this screen time was largely attributed to TV time (Harvey, Chastin, & Skelton, 2013). Approximately 65% of older adults report using computers and 10% reported using computers for greater than 1.6 hours per day. Additionally, younger older adults (<75 years) and men were more likely to accumulate computer time which contributes to overall screen time (+TV time). As computer and tablet-based screen time is becoming increasingly popular, the health risks associated with these devices appear to be dissimilar to that of TV viewing time as computer screen time and internet use has shown a trend toward favorable functional scores (Garcia-Esuinas et al., 2017).

Much of the scientific literature regarding SB has examined the relationship of SB time with personal and proximal factors, but not much information has been provided about the interpersonal, built environment, and social policy factors that influence SB. This is troubling as distal social conditions, which are more difficult to observe, can shape more proximal settings to augment individual susceptibility and contribute to health inequality (Stowe and Cooney, 2014). Further, there was limited information on modifiable determinants and more information needed on contexts and domains of SB. However, SB is a relatively new phenomenon in the scientific literature with most scientific reports occurring in the past decade.

Physical Activity, Sedentary Behavior, and Health

Introduction. Over a half century ago, Dr. Jeremy Morris and colleagues (1953) published findings that bus conductors, who spent their work day walking the length of the bus and climbing the stairs of the double-decker bus experienced half the cardiovascular disease mortality rates compared with bus drivers that remained seated. Based on this observation it was hypothesized that the continual PA of the conductor was protective against the development of cardiovascular disease compared to the continuous sitting of the driver. This was the birth of modern “physical activity epidemiology” leading into more in-depth investigations of PA’s role in physical fitness, morbidity, and mortality.

In 2008, the Physical Activity Guidelines for Older Adults (US Department of Health and Human Services, 2008) made recommendations for both aerobic and muscle strengthening activities to provide substantial health benefits. These recommendations were based on the scientific evidence of PA to alter all-cause mortality, cardiovascular health, metabolic health, energy balance, musculoskeletal health, functional health, cancer, mental health and adverse events (Physical Activity Guidelines Advisory Committee, 2008). However, at the time of publishing these recommendations the evidence on the amount of LPA, MPA, or VPA necessary to maintain physical function and mobility was limited. Also, a standardized definition of SB was not available for another four years which is likely why the 2008 Physical Activity Guidelines makes a general statement to “avoid inactivity”, with no clear indication of how much SB is too much.

Until recently, time spent in LPA was not identified as a significant contributor to health, function, and mortality. Modern advancements in PA monitoring has improved the accuracy and discriminatory capacity of activities in the lower end of the PA continuum. This has strengthened the evidence linking transitions between LPA and SB to health and functional outcomes. Further research is needed to describe the associated health effects of lower intensities on the PA continuum.

With PA and SB being mutually exclusive, reductions in SB will result in either changes in LPA or MVPA during waking hours. Therefore, it is important to highlight the graded dose-response of varying intensities of PA on health and function. Also, given the positive association between comorbidities and functional limitations the maintenance of overall health is vital for functional health. The following section will briefly detail the observational and experimental evidence linking various intensities of PA and SB with health and function, building the evidence for interventions that target along the entire PA continuum.

Moderate-to-Vigorous Physical Activity

MVPA, mortality and health. Findings from the Aerobics Center Longitudinal Study helped to define the current PA recommendations by comparing self-reported PA to cardiorespiratory fitness (CRF) values from maximal aerobic treadmill tests. It was identified that men with low to moderate levels of CRF reported an average of 112 and 130 minutes of walking per week and women with low to moderate levels of CRF reported an average of 128 to 148 minutes per week of walking (Sui, 2007). Previous findings suggested that at least moderate levels of CRF were associated with significant reductions in the rates of premature mortality (Blair et al., 1996; Stofan et al., 1998). Thus, getting at least 150 minutes of moderate-intensity walking per week may result in a moderate level of CRF which is protective from premature mortality.

Physical fitness shows a strong, graded inverse relationship with all-cause mortality, independent of other confounding risk factors (Blair et al., 1989). VPA is a superior stimulus to improve physical fitness with additional health benefits beyond that of MPA participation. In particular, when VPA takes up a larger proportion of total MVPA men, but not women, experienced an additional 4-10 percent reduction in all-cause mortality (Shiroma et al 2014). In a 2011 meta-analysis, 75 minutes of VPA and 150 min of MPA were linked to an 11 and 10 percent mortality rate reduction, respectively (Samitz et al., 2011). Thus greater volumes of MPA, relative to VPA, may provide an adequate stimulus for CVD risk management and prevention of all-cause mortality. Findings from the Women's Health Initiative Observational Study identified that women with increasing quintiles of reported PA energy expenditure had improved risk of coronary events. Further analysis identified that brisk walking with less sitting provided similar risk reductions in cardiovascular events compared to vigorous exercise (Manson et al., 2002).

Both cross-sectional and prospective population-based studies have identified significant associations between leisure-time PA and metabolic syndrome (MetS) (Dubose et al., 2004, Ekelund et al 2005). Physical activity energy expenditure was able to predict progression towards MetS independent of aerobic fitness, obesity or other confounding factors (Ekelund et al., 2005). Participants in the study were free of MetS at baseline and a total of 605 men and women completed follow up at 5.6 years. When split into quartiles of self-reported PAEE, the lowest quartile (<10 kcal/kgFFM/d) experienced significantly greater MetS risk at follow up than any other quartile. According to both self-report and accelerometer-derived MVPA from 2003-2006 NHANES data, men and women that did not meet the PA guidelines experienced significantly greater odds of having MetS. The relationship remained after adjusting for BMI, and was stronger among objective measures of PA rather than self-report.

Lakka and Laaksonen (2007) outlined that evidence from epidemiological studies and randomized controlled trials have shown that MPA, like walking, are just as effective as vigorous intensity activities on improving metabolic risk and CVD risk factors. In particular, increasing daily walking was shown to improve central adiposity (Jakicic et al., 2003), glucose tolerance (Swartz et al., 2003), and blood pressure (Moreau et al., 2001). Woolf-May and colleagues (2011) showed that 24-weeks of moderate intensity walking activities of 150 min/wk at 51 percent of aerobic capacity reduced waist circumference and improved insulin sensitivity, thus reducing the risk of METs.

Aerobic activities that include walking have been shown to be protective against age-related cognitive decline, reducing anxiety and depression, and improving social well-being (McAuley et al., 2000). Proposed mechanisms to explain this include exercise-induced increase in blood circulation to the brain and influences on the hypothalamic-pituitary-adrenal axis, reducing the body’s response to stress (Sharma et al., 2006). Other factors that contribute to PA improvement on mental health include alleviating low self-esteem and improving cognitive function. In a randomized controlled trial including 19-93 year olds, a moderate-intensity exercise group experienced immediate improvements in working memory, affective experience, and reaction times compared to a non-exercising control group (Hogan, Mata, & Carstensen, 2013). Other studies have shown improvements in brain-derived neurotrophic factor which is indicative of brain health (Zoladz and Pilc, 2010).

The relationship between PA, SB, and cognitive function is bi-directional. For example, individuals with higher cognitive functioning may be more physically active or individuals that are more physically active may present greater cognitive function. Nevertheless, PA has been identified as a moderator of executive functioning in the brain which is identified as a complex process of cognitive coordination to achieve a particular goal (Loprinzi, 2016). Further, 65 percent of older adults are multi-morbid with 3 or more coexisting chronic health conditions and multi-morbidity is inversely associated with cognitive function with PA moderating this relationship.

Moderate-to-vigorous-intensity physical activity and function. The independent relationship between physical inactivity, or insufficient exercise, and functional decline is on par with other known determinants of physical function. Cross-sectional findings from the Longitudinal Study on Aging (n=1737) identified that those that reported insufficient exercise had a 20 percent increased odds of functional decline over two years compared to those regularly participating in exercise (Mor et al., 1989). And, those that reported difficulty walking a mile without stopping had a 29 percent increased risk in functional decline compared to those that walk several miles per week. Meanwhile, nearly equivalent magnitudes of risk for functional decline were associated with gender (32 percent), being unmarried (25 percent), and visual impairments (31 percent).

In a prospective study observing nearly 7,000 men and women aged 65+ years and with intact mobility at baseline were followed-up after four years. Approximately 55 percent maintained mobility, 36 percent lost mobility, and 9 percent died without reporting change in mortality. Those that classified as highly active had a 50-60 percent reduced risk of mobility loss over four years compared to a low active group (LaCroix et al., 1993). Other factors that significantly contributed to loss of mobility were smoking status, no alcohol intake compared to small-to-moderate intake, and high BMI compared to moderate BMI.

In the same multi-center, longitudinal study reported by LaCroix and colleagues (1993) reported a hierarchical effect of PA volume and/or intensity on function and mortality across three and six years (Simonsick et al., 1993). Being classified as highly active was linked to reduced risk of developing functional limitations and mortality over three and six years and moderately active was linked to reduced risk of physical impairments over three years, but not six years. Although this study attempted to include various types of PA like housework, gardening, walking, exercise, and sports; a major shortcoming in the methodology was the generic grouping of individuals into inactive, moderately active, and highly active groups. Anyone performing a VPA for any period of time, like a single set of singles tennis was categorized in highly active (16-26 percent), those that did not perform any of the listed activities was identified as inactive (26-32 percent), and all others in the moderately active category. Thus, an individual walking at a light to moderate intensity for 60 minutes per day every day of the week would not be placed in the highly active group.

Using the 2003-2006 NHANES accelerometer data from 1914 older adults, Gennuso and colleagues (2013) identified that meeting the PA guidelines of 150 min per week of MVPA did not protect against the negative associations of prolonged sitting and self-reported physical function or measured cardiometabolic risk factors. In those that were insufficiently active, the odds of reporting functional limitations was significantly reduced by half in the lower three quartiles of SB (<10.64 hr/d). Changes in SB did not yield a significant change in odds ratio for functional limitations in those that were sufficiently active. The findings of this study suggest an additive effect of MVPA and SB, where those that participated in 150+ min of MVPA and had less than 8 hours of SB experienced superior outcomes.

Lastly, it is important to note that a minimal level of muscular strength, muscular endurance, and balance is necessary to perform large multi-muscle dynamic movements that occur in aerobic activities at an intensity of MVPA. Although groups with high aerobic activity have significantly greater muscle mass, strength, and aerobic capacity compared to inactive groups, all measures of fitness continue to decline with age (Crane et al., 2013; Nishiguchi et al., 2014). Whilst approaching the disability threshold with advanced age, the attenuating effect of walking, alone, on the preservation of muscle mass and functioning may not be adequate. Resistance training may serve as a necessary stimulus to maintain an adequate level of muscular strength to escape an approaching disability threshold.

Light-Intensity Physical Activity

Light-intensity physical activity, mortality, and health. Recent evidence suggests that LPA is under-recognized, especially when used to replace SB. Earlier reports provided a 23 percent lower risk of death for those that participated in activities with MET levels of 4.5+, but did not identify a protective association with MET levels below 4.5 with all-cause mortality (Paffenbarger et al., 1993). A significant linear dose-response for total PA energy expenditure per week with mortality risk was reported by Lee and Paffenbarger (2000). When split by intensity, energy expenditure from LPA did not show an association with mortality risk. Conversely, energy expenditure from MPA was significantly linked to mortality risk with VPA providing a stronger graded response. However, the cut-offs between LPA and MPA did not meet the current standardized estimates (4 and 4.5 MET, respectively, versus the current 3.0 METs) and the PA data was collected through questionnaires that relied on recall of blocks walked daily, stairs climbed daily, and recreational PA frequency, intensity, type, and duration. Therefore, the PA measurement techniques used in these studies may not have been as accurate or sensitive to health associations of lower intensity PA as current methods.

Using accelerometry in the 2003-2006 NHANES cohort of adults aged 40+ years, it was reported that those who performed 4 and 5+ hours/day of LPA experienced a 32 and 42 percent reduced mortality risk compared to those that performed < 3 hours/day of LPA, respectively (Matthews et al., 2016). The protective association of LPA was attenuated, but still significant after adjusting for MVPA (21 and 23 percent, respectively). Participation in MVPA was linked to reduced mortality risk even after adjusting for LPA and SB, with a plateau in benefits after reaching 1.5 hours/day in MVPA. In those that were less active (below 5.8 hr/d of total activity), there was a 7 percent increased risk for mortality for every hour of SB. Isotemporal substitution analysis identified that replacing SB with LPA or MVPA is beneficial against mortality risk in the low active group with little benefit in the high active group (Matthews et al., 2016). Collectively, it is suggested that total activity is important for mortality risk which includes both LPA and MVPA during waking hours.

A recent prospective report from the 2003-2004 NHANES data identified that for every 2 minute increase per hour of SB with concomitant 2 min decreases in either LPA or MVPA were linked to an 18% increased mortality risk (Beddhu et al., 2015). Furthermore, trading SB time for low-intensity PA (100-499 cpm), like standing, did not confer any hazard risk benefit. These findings highlight some of the recent advances in discriminatory associations of activities in the lower end of the PA continuum.

Light-to-moderate PA, like walking, may be protective against certain cancers. In women where 5-6 hours of walking per week presented a 24% risk reduction in colon cancer in compared to 0.5 hours of walking per week (Wolin et al., 2007). In a Japanese cohort study, both men and women exhibited an inverse relationship between time spent walking and colon cancer risk (Takahashi et al., 2007). Other studies have found conflicting evidence between walking and suggest greater investigation into the type, intensity, and duration of PA to combat colon cancer risk. A meta-analysis on 31 prospective studies by Wu and colleagues (2013) identified a dose-response relationship between breast cancer risk and PA, with every 4 hours/week of LPA or 2 hours/week of MVPA linked to a 3% and 5% risk reduction, respectively.

When applying non-exercise thermogenesis, it is possible that replacing just 1-5 min/hour of SB with LPA could equate an increased expenditure 200-1000 kcal/week. Meanwhile, if an individual were to take up 150min/week of MPA, or walking at 4.0 METs, this would equate to an additional 600 kcal/week (Beddhu et al., 2015). Therefore, modifying transitions between LPA and SB may be an effective solution at reducing health burdens if following a hypothesis that non-exercise PA-related energy expenditure contributes to unintentional weight gain, development of comorbidities, and premature mortality.

There is limited research that examines the effect of objectively determined SB or LPA on MetS and other CVD risk factors. A systematic review of intervention studies using LPA to affect CVD risk factors identified no significant improvements in body composition, fasting glucose and insulin, cholesterol, or triglycerides and inconsistent findings that LPA affected aerobic capacity in physically inactive adults (Batacan et al., 2015). The results of this review should be interpreted with caution as the effect of LPA on CVD risk factors was primarily assessed in younger adults (18-39 years), many of the studies were of low to fair quality, and consisted of LPA in low doses. Further, the limitation of LPA in addressing these risk factors compared to MVPA in this review assumes that LPA and MVPA are competing interests. Contrary to this, time spent in MVPA should be maintained as SB time is replaced by LPA.

Isotemporal substitution modeling of the 2005-06 NHANES data identified that substituting 30 min of SB with MVPA or LPA provided statistically significant and clinically relevant improvements (2-25 percent and 2-4 percent, respectively) in various cardiometabolic risk factors (Buman et al., 2010). The differing effects of MVPA and LPA can be equated by extrapolating LPA across longer proportions of waking hours. For example, a 90 min change in LPA while replacing SB led to a 6-12 percent improvement in cardiometabolic markers. This indicates that reallocating SB time to LPA while maintaining MVPA may provide clinically relevant improvements in cardiometabolic health factors. Additionally, lower intensities of PA tend to be more effective among populations at increased risk of lower fitness. Additionally, participation in MPA can result in metabolic adaptations though limited compared to more vigorous activities. Nevertheless, these adaptations can result in the same absolute workload being less demanding after continual training.

The inverse relationship between MVPA and cognitive decline in aging has been cited in several studies, with emerging evidence for LPA as a contributor. Two cross-sectional studies with 174 and 188 community-dwelling older adults linked LPA to higher executive functioning (Wilbur et al., 2012; Johnson et al., 2016). Both studies used accelerometer-derived PA across seven days and validated cognitive tests. In a meta-analysis of studies that incorporated walking activities in previously inactive older adults, it was identified that those without cognitive impairment experienced little variation with modest, yet significant improvements in executive functioning (Scherder et al., 2014). However, those with cognitive impairment did not experience these benefits.

Higher levels of fitness which often require greater intensities of PA which has been linked to preserving grey matter volume in the frontal, parietal, temporal and hippocampal regions in older adults (Colcombe et al., 2003; Erickson et al., 2009). How lower intensities of PA translate to improved brain functioning remains to be identified, but may be suggestive of comorbidity reduction or a more robust social life which presents a beneficial effect on cognitive functioning (Wang et al., 2013).

Light-intensity physical activity and function. While doses of exercise that contain higher intensities of PA have been historically noted for a range of physiological benefits and overall longevity, less is known about the associated health benefits of low-to-moderate intensities of PA. In describing the epidemiology of PA and physical function in older adults, DiPietro (1996) discussed the lack of evidence demonstrating the relationship between habitual daily PA levels and the maintenance of physical functioning. A decade and a half later, Paterson and Warburton (2010) again address the lack of evidence linking LPA to function. Publication bias leading to the rejection for studies for not showing significant results and an emphasis of study design comparing MVPA to LPA, rather than LPA to SB were suggested as key contributing factors. As such, greater intensities or volumes of PA are protective against disablement with no clear indication of the minimal intensity needed to maintain function. Among older age groups (70+ years) it is suggested that walking one mile or more may be an effective stimulus to offset disablement (Paterson and Warburton, 2010).

The most common form of PA in older adults is walking which largely constitutes time traversing the life-space, or movements in an area extending from one's home to external geographic regions (May et al., 1985). Reduced life-space mobility is linked to increased SB, decreased LPA and MVPA (Tsai et al., 2016), decreased lower muscle mass (Ikezoe et al., 2011), reduced physical performance (Ikezoe et al., 2016), and self-reported function (Baker et al., 2003).

In a sample of 602 Australian adults aged 36-80 years, there was a significant positive association in light-(<3 MET) and moderate-intensity (≥3 MET) stepping determined by

ActivPal with knee extensor strength, and timed up-and-go in a subsample (n=165) of those aged 65+ years (Reid et al., 2016). The strength of associations between standing, light stepping, and MVPA with physical functioning were not equivalent suggesting differing degrees of benefits when replacing a SB with PA.

Isotemporal substitution modeling is a novel statistical analytical technique that is increasingly being used to assess the association of replacing time spent in one behavior with the equivalent amount of time spent in another acitivity (i.e., 30 minutes of SB reduced and 30 minutes of LPA increased). The implementation of isotemporal substitution modeling in PA epidemiology is described in detail by Mekary, Willet, Hu, & Ding (2009). Isotermporal substitution was used in a sample of 101 community-dwelling older Japanese women with both LPA was significantly correlated with the five-time sit-to-stand test (r=-.203), but did not find a significant change in timed up-and-go, usual and maximal walking speed, and five-time sit-to-stand test when replacing 30 min of SB with LPA. Furthermore, replacing SB or LPA with MVPA resulted in significant improvements in all functional measures with exception to the five-time sit-to-stand. These results are in contrast to the findings of Buman and colleagues (2010) who reported low- and high-LPA were positively associated with better self-reported physical health in 862 older adults. Isotemporal substitution models identified a 0.30 and 0.07 standard deviation increase in reported physical health when replacing SB with high- and low-LPA, respectively. The ratings of physical health with high-LPA were similar to MVPA (0.34 standard deviation increase) with no substitution effects between the two, and high-LPA having associated with higher ratings of well-being. Furthermore, high-LPA was significantly associated with self-reported well-being, while MVPA was not.

Interestingly, there are few studies that assess the association between objective-determined LPA and MVPA in those orthopedic or health-related mobility disabilities which may limit their MVPA participation. Debilitating diseases may include those with arthritis, reduced cardiovascular fitness, comoribidities that result in chronic fatigue, and a frail phenotype. As mentioned in the previous study, the difference in the strength of association between high-LPA and MVPA on self-reported function in older adults was minimal. Therefore, LPA may serve as a suitable stimulus for health and functional related outcomes in populations that are incapable of performing MVPA for bouts lasting at least 10 minutes, or even sporadic bouts of MVPA. However, the validity of using accelerometry to measure PA in some of these populations in free-living environments is yet to be determined.

As previously mentioned in this section, there is still a limited amount of literature linking LPA with health and function. Improving the methods to distinguish and quantify different PA intensities and improved study designs hint towards an association between LPA and physical functioning. The associated health and functional benefits of bolus amounts of MVPA clearly outweigh the benefits of equivalent changes in LPA. In contrast, recent evidence linking SB to poorer health outcomes, independent of meeting the PA guidelines, suggests a need to address SB and LPA time while holding MVPA constant. The following section will highlight the relationship between SB with health and function.

Sedentary Behavior

SB, mortality, and health. In general, those who sit less experience better health outcomes while aging and a better quality of life (Dogra and Stathokostas, 2012; Balboa-Castillo et al., 2011). Public health officials and scientists are searching for effective and acceptable interventions that focus to reduce SB by interrupting postures and/or increasing seated energy expenditure during these SB activities. The primary contexts of SB in older adults include in-home activities like watching television, performing computer tasks, and reading. Alarmingly, older adults watching ≥4hr/day of television resulted in a 50 percent increase in risk of all-cause mortality and 2-fold increase in cardiovascular mortality compared to those watching <2hr/day (Dunstan et al., 2010).

In a 2013 meta-analysis of SB that primarily consisted of studies using self-reported time spent sitting, there was a non-linear dose-response curve where elevated amounts of time spent sitting was linked to all-cause mortality (Chau et al., 2013). Estimated risk for mortality was more pronounced for each hour after 7 hr/d (5 percent increase per hour). The single study that used accelerometry in the meta-analysis presented a stronger relationship between increased sitting time and all-cause mortality (11 percent increase per hour). In this same meta-analysis MVPA attenuated, but did not fully mitigate, the risks associated with overall sitting time (Chau et al., 2013).

A prospective examination of SB from 2001 to 2003 with mortality rates between 2003 and 2011 was performed by Leon-Munoz and colleagues (2013) among a Spanish cohort of 2635 older adults aged 60+ years. Median self-reported sitting time was used to dichotomize groups by excessive SB time and then categorized into groups of consistently sedentary, newly sedentary, formerly sedentary, and consistently non-sedentary. The study identified benefits of being consistently non-sedentary were present even among those that reported above the median in PA participation, with an inverse dose-response relationship between SB time and mortality ($p<0.001$) regardless of PA participation. Within this report it was noted that there was only a modest correlation between MVPA and SB time (rho = -0.28) suggesting that the promotion of MVPA may not necessarily translate to less time in SB.

TV watching, which is a predominant activity performed during SB, has been linked to being overweight/obese (Inoue et al., 2012), increased risk of MetS (Gardiner et al., 2011), CVD incidence (Wijndaele et al., 2011), and mortality (Dunstan et al., 2010). Inoue and colleagues (2012) reported that independent of meeting the PA guidelines, there was a significantly lower likelihood of being overweight or obese in older adults that spent less time watching TV. In nearly 2000 men and women aged 60+ years, Gardiner and colleagues (2011) reported a significant trend for higher levels of TV time with abdominal obesity and impaired fasting glucose. The quartile with the greatest amount of TV time (> 3 hr/d) had a 42 percent increased risk of having MetS than the lowest quartile (< 1.14 hr/d). Meeting the PA guidelines was protective against the presence of MetS with greater TV time, while those who were inactive in the highest two quartiles of TV time (> 2 hr/d) were significantly linked to increased odds of having MetS (77 percent and 104 percent). Interestingly, meeting the PA guidelines and being in the highest quartile for sitting time had greater odds of MetS than an inactive person in the lowest quartile of sitting time. Therefore, an "active couch" potato was at greater risk of having MetS than a "non-exercising busy bee".

Recent experimental models identify a link between insulin action and shared time between SB and LPA, even among moderately active individuals (Lyden et al., 2015). The two-week experiment included seven days of normal free-living activities and seven days of a sedentary condition with instruction to sit as much as possible. Findings from the study showed that a 15 percent increase in SB led to significant increases in 2-hour plasma insulin release with MVPA held relatively constant between the two measurement periods.

How SB is accumulated, is increasingly becoming relevant as a contributor to obesity and cardiometabolic disease. In particular, more frequent breaks may be protective against MetS

(Healy et al., 2008). Therefore, two individuals that accumulate the same overall amount of time spent sitting may have different MetS risks if one has more frequent SB breaks or transitions in a day. Moreover, Chastin and colleagues (2012) presented a direct relationship between SB time and adiposity in older adult men and that less fragmented SB time was linked to a higher total body fat and lower limb adiposity in both men and women. This suggests breaks in SB time may be protective against the accumulation of excess body fat and its associated health risks.

Sedentary behavior and function. The relationship between SB and physical function has come into light in the past decade with studies incorporating both self-reported and objective measures of SB and physical function. The recent identification of independent associations between SB and MVPA with physical function has served as a driving force for SB becoming a public health concern in the elderly. The following cross-sectional and prospective studies will outline evidence linking the independent association of SB with physical function in older adults

In a large cohort of 61,609 women aged 50-70 years from the Women's Health Initiative Observational Study, prospective findings during a 12-year follow up identified a strong association between increasing amounts of SB time and reduced physical function (Seguin et al., 2012). There was a significant dose-response for SB time with the highest quartile of accumulated SB time experiencing a 3-fold greater risk of reporting poor functioning. Although increasing amounts of PA were linked to better functioning in this cohort, every category of PA participation was linked to significantly diminished physical function in women reporting the greatest amount of SB.

The manner of which SB is accumulated, in particular length of bouts and frequency of breaks throughout the day, may have a stronger link to functional health than overall accumulated time spent in SB in a day. Sardinha and colleagues (2015) collected accelerometer data on 215 Portuguese older adults aged 65-94 years and assigned z-scores for their Senior Fitness Test battery results. All results were adjusted for demographic covariates, physical independence, and medical status. The results indicated that breaks in SB were significantly linked to arm strength and five-time sit-to-stand performance and composite z-score of the Senior Fitness Test, even after adjusting for SB and MVPA time. Interestingly, individuals that were below the median breaks in SB (80.4 breaks/day) and that did not meet 30 minutes of MVPA were in the lowest functional category, but individuals above the median in breaks in SB improved function even when not meeting the PA guidelines.

Gennuso and colleagues (2013) studied the association between SB and MVPA with cardiometabolic risk factors and physical function using objective measures of PA and self-reported physical limitations among older adults in the NHANES 2003-2006 cohort. Groups were dichotomized by meeting or not meeting 150 minutes per week of MVPA and split into quartiles for SB. In this sample, approximately 35% were sufficiently active and the average SB time was 9.4 hours per day. Sedentary behavior was found to be linked to number of functional limitations after adjustment for MVPA and MVPA was linked to a number of functional limitations after adjustment for SB. Further, both MVPA and SB held independent associations with weight, BMI, waist circumference, and C-reactive protein. Collectively, these results provide evidence for developing interventions that concurrently target MVPA and SB.

Accelerometer-derived data from the 2003-2006 NHANES and self-reported ADL difficulty identified a 46% greater odds of having an ADL disability for every one hour increase in daily SB time (Dunlop et al., 2015). This effect was attenuated after adjustment for several other confounder including socioeconomic status, health factors, and participation in MVPA. In terms of relative changes in SB time, a 10% increase in SB was linked to a 70% increased odds of having an ADL disability after including the same covariates. The consistent and strong positive relationship between SB and ADLs found in this sample of 2286 adults aged 60+ years and the lack of effect modification with the addition of several covariates suggests the need to look closer into the mechanisms of how SB is detrimental to functional health and the need to develop interventions specifically targeting SB.

Among a British cohort of 60-64 year olds overall SB time was significantly associated to lower grip strength, chair rise, balance, and timed up-and-go (Cooper et al., 2015). Conversely, MVPA and PA-related energy expenditure were linked to improvements in grip strength, chair rise, balance, and timed up-and-go. When SB was adjusted for MVPA, reduced grip strength and timed up-and-go values were no longer significant. When MVPA was adjusted for SB, chair rise improved, timed up-and-go remained, and grip strength and balance were no longer significant.

In an attempt to address “the chicken or the egg scenario” between physical function and SB, Hirvensalo and colleagues (2000) ranked 1109 participants from Finland into four groups based on self-report: intact mobility and physically active, intact mobility and physically inactive, impaired mobility and physically active, and impaired mobility and physically inactive. Compared to the intact and active group, impaired-active had a two-fold greater risk of death and impaired-inactive group had a three-fold greater risk of death in follow up. Also, the impaired-physically inactive men and women experienced 5- and 3-fold increased odds ratios for dependency. Thus, among those with intact mobility, PA did not confer as strong as a benefit as for those with mobility limitations, suggesting that PA participation for those with mobility limitations may prevent further disability or mortality.

A cross-sectional analysis of 602 Australian adults (aged 36-80 years) assessed SB and PA through ActivPal monitoring and performance based measures of physical functioning using TUG and knee extensor strength (Reid et al., 2016). No significant associations were found for TUG with all activity measures (total sitting, prolonged sitting, standing, stepping, light stepping, MVPA stepping, or sit-stand transitions). Knee extensor strength was significantly linked to each additional hour of all stepping, light stepping, and MVPA stepping. Among those aged 65+, TUG significantly improved with each additional hour in stepping (10 percent), light stepping (12 percent), and MVPA stepping (18 percent). Therefore, increased ambulatory activity is linked to better functioning in older adults and younger adults may need more sensitive composite measures of physical functioning to predict these associations.

Furthermore, Chastin and colleagues (2012) assessed the relationship between SB and PA with skeletal muscle quality and body composition in 30 high functioning, healthy older adults. In this study greater SB time was linked to higher body fat percent in the lower limbs and higher lower limb extensor power and frequent breaks in SB were linked to lower total body fat. For men, variance in muscle quality was explained by a combination of SB fragmentation and LPA (27 percent, $p=0.06$), MPA (42 percent, $p=0.02$), and VPA (59 percent, $p=0.03$). These results suggest reducing total SB by introducing SB breaks that include MVPA may be more beneficial to preserving skeletal muscle quality in this highly functioning group of older adults, whereas LPA may be of greater benefit among populations with mobility limitations.

Davis and colleagues (2014) identified that breaks in SB and MVPA contributed to 41.5% of the variance in lower extremity function as determined through the SPPB. Each additional break per hour was linked to a 0.58 point increase on a 12 point scale. In particular, targeting the addition of a PA to provide the SB break may serve as a convenient and practical solution. Using isotemporal substitution models, Kim and colleagues (2015) identified a significant correlation between overall SB time and multiple performance-based measures of physical functioning. Improvements in the TUG was significantly associated to replacing longer bouts of SB with shorter bouts of SB time, whereas substituting prolonged bouts of SB with LPA did not yield significant improved associations with physical function.

Summary. There is a clear hierarchical relationship between various intensities of PA with health and function. Specifically, MPVA is superior to LPA in terms of mortality risk, cardiometabolic health, physical fitness, and function, where increasing amounts of SB are detrimental. Relative to the individual's functional status and/or current level of MVPA, time dedicated towards 30 minutes of MVPA should remain constant while time spent in SB should be replaced with varying amounts of time spent in LPA or MVPA. With LPA serving as a prerequisite to MVPA, individuals with intact mobility limitations may experience greater effect sizes for changes in LPA. Lastly, most of the studies linking PA and SB with health have heavily relied on observational methods which limit the interpretation of the findings which are likely bi-directional and could be exposed to reverse causation. To better understand the independent effects of SB, LPA, and MVPA on function in older adults, observational studies should account for the time displacement of exchanging mutually exclusive activities in the day and further strive to conduce randomized controlled intervention studies.

Summary of Epidemiology of PA and SB in Aging

Time spent in MVPA and LPA progressively decrease with age, while time spent in SB increases. This contributes to an older adult population characterized as less likely to fulfill the PA guidelines while accumulating greater prolonged and overall time spent in SB which can compound the effect of aging on skeletal muscle and overall function. This accelerated loss of function is linked to premature mortality and loss of mobility and independence in late life, which may be reversible by incorporating changes in daily habits of (in)activity.

Moderate-to-vigorous-intensity physical activity provides clear benefits to health and functioning, but there are several reports that link SB to ill health and function, even when physically active. Also, increased MVPA does not necessarily translate to decrease SB, suggesting a need to incorporate frequent bouts of LPA to interrupt SB while holding MVPA constant at the recommended dosage. Lastly, several factors can influence participation in high amounts of SB. Future interventions should target both individual levels of SB in the homes in times of isolation and during social interactions of older adults. Also, distal influences like changing social norms that promote movement during otherwise inactive periods of leisure time may be an effective, but difficult to measure approach.

Sedentary Behavior and Light Physical Activity Interventions

Introduction

Most of the negative associations with SB have been linked to cardiometabolic risk and mortality in older adults, but recent inquiries using more sensitive measurement techniques and better study design are mounting more definitive evidence between SB and physical function. Observational studies and brief experimental studies have provided a rationale to develop interventions to reduce SB in older adults and those at-risk for mobility disability. The current evidence suggest that sitting more predisposes toward a risk of developing an inactive phenotype with associated physical limitations, leading to more time seated and a vicious cycle toward premature disability and mortality risk. The benefits of intervening occur at all times along the life continuum, but older adults represent an at-risk group with reduced physiological reserves and increased exposures to SB time.

Interventions designed to reduce or interrupt SB are relatively new and have not come without difficulties. When developing SB interventions, one must consider the age, health status, social and environmental contexts, and life roles which can all contribute to the acceptability and effectiveness (Manini et al., 2014). For example, older adults may experience greater effects on functional outcomes per unit change in SB, but interventions that have been developed for younger populations many not translate as acceptable among older populations. Also, changes in SB are not inevitable when implementing either SB or PA interventions as at least one study has shown no significant change in SB time following an intervention (Evans et al., 2012). Only a handful of intervention studies have investigated the joint effects of reduced SB and increased PA, with even fewer incorporating older adults and reporting functional outcomes. The following section will review intervention studies that aim to reduce or interrupt SB in older adults.

Behavior Change Theory

To date, there has been wide heterogeneity in the effect size of interventions focused on reducing SB. Changes in SB are not guaranteed, with respect to an intervention by Evans and colleagues (2012) recognizing no impact on SB time following an intervention. This speaks to the complexity of SB and need for identifying behavior change strategies to appropriately address SB, especially when pertaining to a specific population with social and environmental factors serving as significant contributors to SB.

Gardiner and colleague (2016) performed a review on behavior change strategies used in SB interventions on adults. Of the 26 eligible studies, approximately half were worksite based and only two incorporated older adults. Effect sizes in the studies reported in this review presented heterogeneity which may be a result of a majority of the studies in this review using interventions that focused primarily on PA (61 percent), a variety of education and behavior change techniques used, and scant randomized controlled trials. Using a ‘promise ratio’ based on number of promising interventions divided by the number of non-promising interventions using the same intervention function was the evaluation method for intervention potential (Martin et al., 2013). Analysis in this review identified that self-monitoring, problem solving, modifying social and physical environments, and education on health impact of SB were promising intervention functions. Of these, self-monitoring and changes to the physical environment were the most promising and were recommended to be investigated in future research. Also, it was suggested that future studies focus specifically on targeting SB rather than assume PA will alter SB, appropriately incorporate and perform behavior change theoretical constructs, and use randomized controlled trial designs.

To date, there are still limited interventions targeting SB, but efforts have been made to align behavior change theories. Michie, van Stralen, & West (2011) propose the use of a Behavior Change Wheel to develop effective interventions and avoid misguided behavior change techniques. This framework incorporates one or more of nine functions of behavior change, but may be helpful in addressing whether an intervention function aims to educate, persuade, or train individuals to reduce SB. By educating, you are assuming that the individual did not previously know the health consequences of SB, persuasion techniques may be used to address previous perceptions and emotions about SB, and training may focus on skill development to improve self-efficacy and self-regulation.

To address motivational processes underlying older adults' SB, a dual-process theory of motivation that can be incorporated into interventions. Dual-process theory includes reflective and automatic process with reflective processes representing intended actions that are conscious and volitional; whereas, automatic processes are habits that are nonconscious and unintended (Conroy et al., 2013). Maher and colleagues (2017) used the Health Action Process Approach (HAPA) as a social-cognitive theory approach to target reflective processes, and assumed a change in behavior would reflect on habit to augment automatic motivation processes. To bridge the intention-behavior gap, a phenomenon to describe the lack of translation of counter-habitual intentions to reality, the authors incorporated individualized detailed plans for change with HAPA. Using cost-effective resources that included recorded videos to disseminate SB information and coaching, the authors found this approach to be feasible, practical, and effective in older adult communities. Although the significant changes in SB were only measured immediately following the two weeks of training and may not be reflective of lifestyle changes, the fact that change happened suggests that the educational and motivational components did translate. Further work is needed to address how to maintain SB reductions in the long term.

Physical Activity Interventions on Sedentary Behavior

To date, most of the interventions that have been designed to address reductions in SB have targeted working-aged populations. Prince and colleagues (2014) performed a systematic review on the effectiveness of PA and SB interventions to reduce SB time. In general, the authors highlighted that 29 of the 43 PA interventions showed no significant difference in SB (mean difference 19 min/d), seven of the 14 studies that combined PA and SB reported no significant difference in SB time (mean difference of 35 min/day in SB time), and one of the six SB interventions reported no significant difference (mean difference of 91 min/day). Further, of the 66 studies that met the inclusion criteria, 33 were included in meta-analysis and only two involved older adult samples.

Likewise, Martin and colleagues (2015) performed a meta-analysis on the potential of interventions to reduce SB time in adults. The meta-analysis included 34 studies including PA interventions, SB interventions, combined PA/SB interventions, and lifestyle interventions (that include PA, SB, and PA/SB interventions). Overall, intervention groups experienced a reduction of SB time by 22 min/d (34 studies, n=5868). Interventions specifically targeting SB (2 studies) significantly reduced SB time (mean difference, 95 percent CI: -42.2 min/d, -78.9 to -4.6) and lifestyle interventions (20 studies) significantly reduced SB time (-24.2 min/d, -40.7 to -7.7). There was no statistical significant effect to reduce SB time in PA interventions (9 studies; -8.34 min/day, -36.02 to 19.34) or joint PA/SB interventions (3 studies; -34.6 min/d, -173.9 to 104.8). However, of the 35 studies included in this meta-analysis, only seven incorporated older adults with all seven focusing solely on PA interventions. Findings were consistent with Prince et al. (2014) noting the importance of targeting the specific behavior intended to change (PA or SB), with discrepancies primarily in the categorization of the intervention types.

Cai and colleagues (2016) performed a meta-analysis on randomized controlled trials that incorporated step counters (pedometers or accelerometers) and reported an effect on SB either through self-report or objective measurement. Of the 15 studies included with 3262 participants, eight used subjective reporting of SB, six used objective measures, and one used both. The meta-analysis identified a small but significant effect size (Cohen's d=0.20) that was equivalent to a 23 min/day reduction in SB compared to controls. The effect size was greater when incorporating targeted step counts and using objective measures which may be more sensitive and/or more accurate in detecting change than subjective measures for SB. Once again, only two of the 15 studies involved older adults both of which focused on PA interventions (Mutrie et al., 2012; Suboc et al 2014).

Suboc and colleagues (2014) randomized 114 inactive older adults into 3 groups: no intervention, pedometer only, and pedometer with interactive website. The study authors reported a significant decrease in overall SB time for the entire cohort (23.6 min/d) during the 12-week intervention period with no significant difference between groups. No change in LPA or VPA was reported with a significant increase in MPA ($p<0.001$) in the pedometer and pedometer with website group. Mutrie and colleagues (2012) used a two-arm 12-week intervention across 24 weeks aimed at increasing step-counts. The two groups were staggered with the intervention group starting immediately and ending at the 12th week with follow up at the 24th week and the control group beginning at the 12th week and ending at the 24th week. Both groups significantly increased step counts by approximately 2000 steps/day with no difference between the two with the intervention group maintaining steps at 24 weeks ($p=0.65$ for difference). Both groups experienced reductions in SB during the intervention period and the intervention group maintained this SB reduction at the 24 week follow-up. Thus, the incorporation of light-to-moderate intensity walking did not result in a compensatory increase in SB time which has been suggested as a possible confounder with higher intensities (Chastin et al., 2012).

Sedentary Behavior Interventions on Sedentary Behavior

The handful of SB interventions that have targeted older adults specifically have shown modest success with self-reported reductions of 9-76 min/day and objectively measured reductions of 24-35 min/day. Rosenberg et al (2015) used a non-randomized one-arm study design of overweight and obese older adults to test the effects of reducing total SB time and increasing sit-to-stand transitions. ActivPal output identified that after 8-weeks of intervention sitting time significantly decreased by 27 min/day, sit-to-stand transitions increased by two per day, and standing time increased by 25 min/day ($p<0.05$). Interestingly, both LPA and MVPA significantly improved as well as gait speed, self-reported sitting time, and depressive symptoms ($p<0.05$). These findings provide an alternative perspective to improving PA, by targeting SB reductions. But future studies should include control groups and larger sample sizes to match the large number of analyses. Acceptability was high with this intervention, with a majority of participants reporting finding self-monitoring logs as helpful.

Gardiner et al. (2011) used a single face-to-face consultation for goal-setting and a single motivationally-based feedback report in the mail with 59 older adult participants targeted at reducing SB. Constructs from social cognitive theory and behavioral choice theory were included a target a 5 percent reduction in SB by standing up and moving after every 30 min of sitting. Primary outcomes of SB, LPA, and MVPA were assessed through accelerometry (GT1M) during pre and post intervention periods (six days monitoring period). Pre-post intervention effects indicated daily SB time was reduced by 3 percent of wear time ($p<0.001$), SB breaks increased by 4 percent per day ($p=0.003$), daily LPA increased by 2.2 percent of wear time ($p<0.001$), and daily MVPA increased by 1 percent of wear time ($p<0.001$). Nearly all participants reduced SB time (84.7 percent) and one-in-five exceeded the 5 percent goal. Interestingly, average SB time began to rise on the third day post-intervention suggesting a need for continued contact with participants. Lastly, this study did not contain a control group and was relatively small. However, it provided relevant information on the approach of introducing a SB intervention to older adult populations.

Similarly, Fitzsimons et al. (2013) used a one-arm experimental study to test the effect of individualized consultation using feedback from an ActivPal monitor to target SB reductions in older adults. Twenty-four individuals participated in this small pilot project which resulted in a significant 24 min/day reduction in sitting/lying time (2.2 percent reduction, p=0.042) and a significant increase in stepping by 13 min/day (p=0.044). Subjective data collection suggests that changes in transport method and TV watching may have contributed to these changes.

Just as different PA types are incorporated into interventions, characteristics of SB can lead to different approaches of intervening on SB time. Specifically, SB can be targeted in different domains (home, occupation, travel, leisure) and by targeting overall reductions in time, interrupting prolonged bouts, or increasing breaks or transitions. Different SB reduction techniques were assessed for efficacy, feasibility, and acceptance in a randomized controlled trial of 30 adults (15 working/15 non-working) aged 50-70 years (Kerr et al., 2016). Participants were randomized into one of two groups: 2 hour reduction in daily sitting or 30 additional sit-to-stand transitions per day. Participants were monitored objectively using ActivPal at baseline and following two weeks of intervention. Changes in targeted behavior change were exclusive without cross-over to the other. In general, the “reduced sitting” group effectively reduced sitting by two hours with no change in sit-to-stand transitions. Meanwhile the “increased sit-to-stand” group did not change sitting time but did significantly increase sit-to-stand transitions (less than 30 per day).

Of the SB interventions in older adults, most are still in the early stages of development and dissemination with most of the reporting including feasibility, acceptability, and efficacy. Reporting on the effectiveness of SB interventions to alter clinical outcomes should be more pronounced in the next few years.

Recently, Maher and colleagues (2017) performed a randomized control trial to determine the feasibility and efficacy of reducing SB in older adults. The intervention group participated in a five part process that led participants to evaluate their own SB time through self-report, watch a video on normative SB values and age-related trends, educated on outcome expectancies of LPA and SB, performed action planning for reduce SB with a 14 day follow-up to address barriers, and targeting behavioral goals (stand or step for 10 min during each waking hour or limit SB to less than 8 hr/d). A majority of the 42 older adults in the study spent at least 11 hours/day in SB at baseline and experienced an average reduction of 132 min/weekday in SB time the week following program delivery. This study was limited by a small sample size and very short post-intervention assessment. However, the short term changes in SB indicate that the ability of the videos to disseminate information on SB in community-dwelling older adults was a feasible and effective method. Another layer of intervention delivery may be necessary to maintain adherence for lifelong change.

Gibbs and colleagues (2016) compared the effects of specifically targeting reduced SB in a ‘sit less’ group versus targeting the increased MVPA in a ‘get active’ group on measures of physical function in community-dwelling older adults (mean age: 68 ± 7 years). The authors hypothesized that the ‘sit less’ group would decrease SB time and increase MVPA greater than the ‘get active’ group. Thirty-eight inactive older adults were randomized into one of the two groups with an intervention period of 12 weeks where participants were motivationally coached to reduce SB or increase MVPA on a weekly basis from weeks one to four, and bi-weekly from week five to 12. Interventionists were able to facilitate weekly interactions with feedback from objectively-determined PA and SB data using a SenseWear Armband. Each group achieved their respective goals after 12 weeks, including a one-hour reduction in SB time for ‘sit less’ and meeting 150 min/week of MVPA in ‘get active’. After adjusting for total wear time, the ‘get active’ group increased MVPA by 67 min/week ($p=0.02$) and 10-min bouts of MVPA by 75 min/week ($p<0.001$) with no change in SB time. The ‘sit less’ group did not show significant changes in SB time, total MVPA, or 10-min bouts of MVPA. Performance-based measures of function included the 400m walk test and the SPPB with neither group significantly improving in the 400m walk test, but the ‘sit less’ group significantly improved in the SPPB by 0.5 points. Improvements in chair rise ability primarily drove the changes in the SPPB, which may be driven by specificity of training from interrupting sitting bouts. In summary, these findings suggest that introducing a SB intervention is not effective at increasing MVPA, and likewise a MVPA intervention is not effective at reducing SB. Without employing a two-by-two factoral design, the distinct contributions of SB and PA on function could not be teased out, but these results do highlight that individually focused SB or PA interventions do not result in cross-training effect.

Kozey-Keadle and colleagues (2014) assessed the combined and independent effects of exercise training and reductions of SB on cardiometabolic risk factors in older adults across 12 weeks using four groups: exercise training only, reduced SB time training only, exercise + reduced SB training, and a control. The exercise and reduced SB training group experienced significantly increased time spent in MVPA lasting 10 min or more, non-exercise MVPA, and reduced SB time; whereas the exercise only group only improved in MVPA lasting 10 min or more, but not non-exercise MVPA or SB time. The reduced SB group saw reductions in SB by 7 percent and increased total daily MVPA by 27.9 min. Measures of aerobic capacity and BMI were significantly improved in both exercise groups (with and without SB reductions). Also, the reduced SB group averaged a 48 min/day reduction (-7 percent) in SB time and increased total MVPA from 6 min/day to 28 min/day with no significant change in a majority of the cardiometabolic health outcomes. The authors hypothesized that incidental PA, as witnessed in the reduced SB group, may be sufficient to maintain, but not an appropriate stimulus to improve aerobic fitness and functioning. These findings have been corroborated by McGuire and Ross (2011) that found in a cross-sectional analysis of incidental PA that sporadic MPA, but not LPA, was an independent predictor of cardiorespiratory fitness. However, of particular importance is that this sample was a highly functioning sample of 57 middle aged adults (mean age: 43.6 ± 9.9 years).

Combined Sedentary and Physical Activity Interventions on Sedentary Behavior

An 8-week empowerment intervention on SB, PA, and psychological health was performed by Chang et al. (2012) to determine the effects on hypertension in a small sample, quasi-experimental design (experimental group n=27, control group n=21). The experimental group went through 8-weeks of lifestyle modification training that included goals at reducing TV time or decreasing SB time, group discussion, and exercise training that included aerobic and muscle strengthening activities. Following the 8-weeks of training the experimental group experienced reduced mean difference in self-reported sitting time of 77.6 ± 70.7 min/day compared to a control group that experienced a 8.6 ± 90 min/day reduction in SB time (p=0.004). PA was also significantly increased with a significant group difference (p=0.047).

King et al. (2013) compared three motivationally driven behavior change apps in their ability to increase PA and reduce SB. Key elements of these apps included goal-setting, self-monitoring, and active problem solving. Specifically, goal-setting could include either a targeted goal of working towards 150 min of MVPA or a 10 percent reduction in SB by the end of the study. The goals were administered in a graded fashion to increase personal self-efficacy. Also, feedback on daily activity or sedentariness was provided for the user along with problem-solving strategies. Across the 8-week study all three apps reported significant mean increases in weekly MVPA (group mean increase: 100.8 +/- 167 min/week, $p<0.0001$) with no difference between apps. Also, time spent in front of the television significantly decreased by 29 min/day, with no difference between apps.

Interventions that incorporate MVPA have consistently been identified as promoting improved physical fitness to preserve functional capacity reserves. It was previously perceived that LPA may not be a sufficient stimulus to affect physical fitness or functional reserves. However, more accurate and sensitive measures are beginning to suggest that transitions between LPA and SB may be predictive of health and physical functioning in older adults, independent of time spent in MVPA (Buman et al., 2010; Kim et al., 2015). The following section will highlight the current evidence for improving physical functioning through LPA interventions in older adults. In a review of SB in older adults, Wullems and colleagues (2016) predict that breaking SB with LPA may serve as a promising strategy with more prominent effect sizes in older adults. Furthermore, Manns, Dunstan, Owen, & Healy (2012) suggest that targeting increases in ‘non-exercise’ PA by reducing SB and increasing LPA may serve as a relevant place to begin intervening in those with mobility limitations.

The substantial benefits of PA for the maintenance and improvement of mobility in older adults is well understood, particularly among moderate and vigorous intensities. Pau and colleagues (2014) performed a randomized controlled trial to quantitatively assess the effects of

12-week LPA and VPA interventions on measures of balance, gait, and sit-to-stand (STS) performance in healthy older adults. All study participants in three weekly sessions across 12-weeks, each consisting of a warm-up, a workout phase of aerobic and anaerobic exercises using steps, resistance bands, and balance drills with intensity determined by percent heart rate reserve, and cool down. Only the VPA group significantly improved in most gait assessment parameters and STS. The LPA group only improved in gait swing phase duration and both groups improved in postural sway when eyes were closed. While these findings are important when considering the development and introduction a prescribed dose of PA within a particular, planned segment in the day, these findings do not address the distinct health consequences of how the remainder of the day is distributed in SB and PA. Therefore, it is suitable that VPA take priority over lower levels of PA when targeting specifically desired outcomes from a PA prescription. When coming from an approach of reducing SB, the comparison of LPA and MVPA should be scaled to an approach of practicality in performing and feasibility of delivery in both healthy and mobility limited older adults.

Light-intensity physical activity and non-exercise PA are more likely to present beneficial characteristics in older adults and those presented with mobility limitations in late life than younger adults (Manns et al., 2012). Cross-sectional design identified that increasing levels of LPA was linked to higher scores for functional fitness, independent of MVPA (Blair et al 2015). Longitudinal analysis identified that increasing higher LPA with no change in MVPA was linked to better functional scores in cancer survivors compared that those that decreased or maintained MVPA (Blair et al 2015). These findings indicate that shifting individuals that are high in SB toward LPA may be linked to improved functional scores. Moreover, a group of frail older adults that participated in a three-month supervised LPA exercise program experienced a significant improvement in the physical performance test compared to a home-based flexibility group (Brown et al., 2000).

Among the LIFE cohort, Bann and colleagues (2015) investigated the cross-sectional relationship of SB and LPA on obesity and muscle strength. Higher body fat and limited grip strength are characteristic age-related changes in body composition which contribute to a phenotype resembling dynapenic (or sarcopenic) obesity and is linked to functional impairment and disability. Greater time in LPA and lower time in SB were linked to lower BMI. After adjusting for BMI, time spent in higher intensities of LPA were linked to greater grip strength in men, but not women. TV time was positively associated with BMI. These findings suggest that replacing time spent viewing TV could be replaced with a LPA to improve body composition and muscle strength.

Recent efforts have been made to make activities typically spent sedentary more active. This adds convenience to the practicality of the intervention for only having to incorporate one type of behavior change with PA added to a SB, rather than focusing on reducing SB and increasing PA. However, for participants to adhere to the program the underlying tasks should go relatively uninterrupted.

Considering observational data suggesting that TV watching time is positively correlated with age in older adults (Gardner, Iliffe, Fox, Jefferis, & Hamer, 2014) and that patterns of SB are more important than total SB time (Gennuso et al., 2016), introducing a LPA to TV commercials may be present a convenient point-of-action prompt to break up times spent in SB. Steeves and colleagues (2012) compared two groups a TV commercial stepping group to a standard walking 30 min/day group over six months. Main findings indicated that both groups significantly increased daily step counts by approximately 60 percent and there was no significant difference between the two groups. Secondary benefits of the intervention included significant reductions in percent body fat and body circumferences, with no changes in TV viewing time or dietary intake

Summary of SB and PA Interventions

It must be clearly stated that when given an opportunity to perform a bout of PA, higher intensities are superior in altering physiological functioning than lower intensities. This definitive evidence has driven a majority of interventions to be developed from a perspective that if incorporating PA into someone's day, MVPA is the *best buy* option. However, even among those that meet MVPA recommendations there is a risk of participating in high amounts of SB (Gennuso et al., 2013; Chastin et al., 2012) or with minimal breaks in the SB (Sardinha et al., 2014). The exclusivity of targeting either PA or SB on changes to their respective behaviors suggest joint interventions are necessary to promote significant changes in exercise-related MVPA, incidental MVPA, and reduced SB (Kozey-Keadle et al., 2014). Therefore, time dedicated towards MVPA should remain while interventions are developed to promote an optimal balance of non-exercise PA and SB. Among populations where MVPA is not a practical approach due to current physical capacity or other constraints, interjecting PA of any intensity into time otherwise spent in prolonged bouts of SB is likely to be beneficial with LPA adding convenience. Furthermore, the modest effect sizes and clinical relevance of LPA may increase in older adult populations, and in particular those with existing mobility limitations. The causal explanation of the independent links between SB and different intensities of PA with physical function are not clearly defined. To better understand the cause and effect relationship, more randomized controlled trials are needed with primary outcomes including functional outcomes, more factorial study designs are needed to discern independent and combined effects of PA and SB, more studies are needed in older adults and in those with mobility limitations, and studies should be guided by behavior change theoretical constructs that are appropriately matched to intended outcomes of the intervention.

Overall Summary

Older adults spend the greatest amount of time in SB, representing between 65-80 percent of their waking hours spent sitting and SB has been consistently negatively linked to increased prevalence of comorbidities, musculoskeletal health, body composition, physical function, and quality of life. Physical activity interventions have not been effective at simultaneously reducing SB and increasing PA, likewise SB interventions do not result in a significant cross-over effect.

Doubling the average of 1-3 percent of waking hours spent in MVPA in older adults may provide an effective stimulus to promote maintenance of muscle function, but may not be a feasible approach due to physical or social constraints. Furthermore, the adoption of more vigorous activities may lead to spontaneous compensatory changes including longer sitting bouts with less fragmentation which is linked to increases in health detriments. Therefore, future interventions focused on improving the health risks associated to either physical inactivity or prolonged sitting should concurrently target both behaviors, otherwise risk undermining the intended functional improvements.

There is a consistent, strong inverse relationship between LPA and SB. Epidemiological and experimental evidence suggest that a balance between LPA and SB that favors the former is associated with improved cardiometabolic biomarkers (Healy et al., 2008; Healy et al., 2011) and physical functioning (Buman et al., 2010). Additionally, LPA may be a feasible mode of PA to replace SB while performing typical activities spent sitting in the home. Therefore, we aim to introduce LPA to activities that would otherwise be categorized as a SB, without the intention of replacing MVPA to improve function in mobility limited older adults.

The following chapters represent a series of research studies guided by this literature review to explore the impact of replacing SB with LPA on measures of physical functioning in older adults. These studies are progressive, including an observational investigation using cross-sectional design on accelerometer-derived measures of SB and PA with a variety of physical function measures, an exploratory study to identify the in-home use of a portable elliptical device to replace SB with a seated LPA, and an intervention study to determine the effect of replacing a SB with a seated LPA.

CHAPTER III: ISOTEMPORAL SUBSTITUTION OF SEDETNARY BEHAVIOR AND PHSYICAL ACTIVITY ON FUNCTION

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ABSTRACT

The amount of time spent in sedentary behaviors (SB) progressively increases with age, while reducing time spent in light (LPA) and moderate-to-vigorous physical activity (MVPA). These trajectories in PA and SB are linked to accelerated reductions in physical functioning. PURPOSE: To examine the association of substituting SB time with LPA and MVPA on physical function in older adults. METHODS: Ninety-one older adults (mean age: 70.7 ± 10.2 yr) wore a hip-mounted accelerometer to measure SB, LPA, and MVPA time. Measures of physical function included a 400m walk test (400W), usual gait speed (UGS), and 5-time sit-to-stand (5xSTS), and the short physical performance battery (SPPB). Isotemporal substitution regression modeling was performed to assess the relationship of replacing the amount of time spent in one activity for another. RESULTS: Replacing 30 $\mathrm{min \cdot d^{-1}}$ of SB with LPA was associated with a significant improvement in 400W ($p = 0.0497$), while MVPA resulted in a significant improvement ($p < 0.01$) in 400W, UGS, 5xSTS, and SPPB. Replacing 60 $\mathrm{min \cdot d^{-1}}$ of SB with 10 $\mathrm{min \cdot d^{-1}}$ of MVPA and 50 $\mathrm{min \cdot d^{-1}}$ of LPA was associated with significant improvements in the 400W, UGS, and 5xSTS ($p < 0.05$). Meanwhile, as little as 5 $\mathrm{min \cdot d^{-1}}$ of MVPA and 55 $\mathrm{min \cdot d^{-1}}$ of LPA was linked to a 78% increased odds of scoring with good function in the SPPB ($p = 0.0247$). CONCLUSION: Replacing SB with LPA was linked to a significant improvement in the 400W, but not the other brief functional measures. Mixed doses of LPA and MVPA may add flexibility to interventions targeting reductions of SB in older adults for clinically relevant improvements in physical function.

KEYWORDS: sitting, aging, activity monitoring, exercise, physical function

INTRODUCTION

Physical activity (PA; any bodily movement) and sedentary behavior (SB; a seated/lying activity with an energy expenditure of ≤ 1.5 MET) are identified as key predictors of skeletal muscle atrophy and functional decline with aging (1). Time spent in SB is positively associated with age (2), often including increased durations of time spent in activities like watching television, reading, and computer use in the elderly (3) and has been linked to diabetes (3), cardiovascular disease (4), functional limitations (5), and premature mortality (6). In particular, for every one hour increment in TV watching there is a reported 11% and 18% increased risk for all-cause and cardiovascular disease-related mortality, respectively (7). While the mechanisms linking negative health outcomes to SB are not fully understood, the relationship appears to occur independent of participating in recommended amounts of moderate-to-vigorous intensity physical activity (MVPA) (6, 8), suggesting a distinct physiological pathway from the benefits of the PA to health (9).

Aside from SB, light-intensity physical activity (LPA; e.g., household chores or light walking) and MVPA (e.g., brisk walking, cycling, stairs, or running) make up the remainder of total daily activities and time spent in these activity domains generally decline with age (10). The contribution of LPA to health and functional capacity in older adults is not well established and previously was regarded as an inadequate stimulus to promote health and functioning (11). As SB-related health risks became apparent in the literature the importance of LPA has come into question as a means to replace SB. While the evidence linking LPA to health and functioning is limited, there is preliminary evidence linking LPA with benefits in physical health, such as body mass index (BMI), handgrip strength, and self-reported lower-extremity function (5, 12). Also, LPA may serve as a prerequisite to MVPA participation which is positively associated with improved physical function among older adults (13, 14). However, these MVPA-related benefits may be minimized or canceled out by prolonged bouts of SB suggesting a need to concurrently target and modify SB, LPA, and MVPA behavior (5, 6, 88).

Age-related trajectories in PA have identified that greatest proportion of increased SB comes from loss of LPA and time spent in MVPA is progressively transferred to SB, rather than LPA (15). While discrepancies in the health effects of LPA have been found in previous investigations, these reports may have underestimated the impact of LPA by not measuring the relationship of transferring time spent in one activity to another. Specifically, traditional multivariate regression has been used to isolate the relationship of a single activity (i.e – SB) while adjusting for time spent in another activity (i.e. – MVPA) as a confounding variable, rather than accounting for displaced time. Isotemporal substitution modeling is a novel statistical approach in epidemiology that addresses the more practical question of the potential relationship of replacing time spent in one activity type to time in another activity (16). Isotemporal substitution is particularly valuable in addressing the co-dependence of SB, LPA, and MVPA within a finite amount of time in the day, and the independent and contrasting effects of SB and PA on function (17). Further, only one paper has cited isotemporal substitution with functional outcomes (18) with a paucity of evidence comparing the relationships of LPA and MVPA on health and functioning in older adult populations. Accordingly, the purpose of this study is to identify the relationship of reallocating various time increments of SB, LPA, MVPA with measures of physical performance in community-dwelling older adults.

METHODS

Participants

One hundred and five able-bodied community-dwelling men and women aged 50-90 years from the Greater Milwaukee area were recruited to participate in this observational study. Recruitment strategies included the circulation of flyers in the surrounding community, university buildings, and local senior centers, lab website postings, and informational fall-risk screenings at local Senior Centers and assisted living communities. Participants were excluded if they have had any neurological or functional impairment that would preclude them from participating in physical activity. The study was approved by the University of Wisconsin-Milwaukee Institutional Review Board and informed consent was obtained from all participants in the study.

Overview

Within four weeks of being screened, individuals visited the Physical Activity and Health Research Laboratory on two occasions and the Neuromechanics Laboratory on one occasion. During the first visit anthropometric measurements were obtained and participants were given verbal instruction on how to wear the physical activity monitors. Following a 7-day monitoring period, the participants returned to the university setting to perform a further testing that included the functional performance-based assessments.

Measures

Anthropometrics and body composition. A physician's scale (Detecto, Webb City, IL) and stadiometer (Continental Scale Corporation, Bridgeview, IL) were used to measure body weight and height, respectively, and BMI was calculated ($kg \cdot (m^2)^{-1}$).

Physical activity. A hip-worn accelerometer (Actigraph GT3X+, Pensacola, FL) was worn for seven consecutive days to collect human movement. Study participants were instructed to wear the accelerometer on their right hip for all waking hours. Data was collected at a sampling frequency of 80 Hz with a band pass filter of 0.25-2.5 Hz to include only human ambulatory movement. Raw accelerometer data was collected and analyzed in one-minute epochs using the ActiLife software (Pensacola, FL). Activity cut-points recommended for adults were used to determine SB (< 100 counts per minute), LPA (100-1951 counts per minute), and MVPA (≥ 1952 counts per minute) (19-21) and a wear time classification algorithm (22) was used along with personal logs to determine valid wear time. While accelerometry is a valid and reliable method of measuring SB and PA, there is not a solidified count per minute cut-point for activity intensities in older adults (23). As such it was decided to use the general practice cut-points for all adults in this sample (19).

Physical function. The Short Physical Performance Battery (SPPB) was administered according to the procedures described by Guralnik et al. (24). The SPPB consists of three tasks designed to assess walking speed, ability to rise from a chair, and maintain standing balance. Briefly, walking speed was tested by recording the faster of two trials while performing a preferred and maximal walking speed. Participants were asked to stand-up and sit-down five times as quickly as possible from a straight-backed chair to determine chair rise ability. The time to complete the five repetitions was recorded and assigned a score. Lastly, for balance participants were evaluated on how long they could remain in a full-tandem (toe of one foot directly behind the heel of the other), semi-tandem (toe of one foot even with heel of the other), and side-by-side (heels of both feet even) standing position. The maximum time spent in each position was 10 seconds (s). In the SPPB, a score of 0-6 is designated as a poor performer, a score of 7-9 as a moderate performer, and 10-12 as a good performer. The SPPB has been identified as a valid and reliable measure of functionality and mortality in older adults (25).

The 400-meter walk test (400W) was performed along a pre-determined walking course in a university building corridor covering a distance of 400 meters (m). Participants were asked to complete the test as fast as possible and allowed two opportunities to stop and rest during the test if needed. One trial was attempted by each participant with a researcher recording time to completion with a stopwatch. If the course was completed, the distance was divided by the time to completion to provide a value in $m \cdot s^{-1}$. The 400W has been identified as a valid and reliable measure of physical function in older adults (26).

For usual gait speed (UGS) participants were asked to perform a preferred walking pace across an eight foot course. The faster of the two measurements was recorded and used for analysis. The distance of the course was divided by the time to complete the course providing a recorded measurement in meters per second ($m \cdot s^{-1}$). Walking at a normal pace has been identified as a valid and reliable performance test for determining level of physical function, deterioration and improvement (27).

The five-time sit-to-stand (5xSTS) was used as a performance measure to assess lower leg power and chair rise ability. The participant was asked to stand-up and sit-down five times as quickly as possible from a straight-backed chair. The chair was placed against a wall and the participant was told to fold their arms across their chest. Time to completion of the five repetitions was collected by a researcher using a stopwatch and recorded in seconds (s). The 5xSTS has been identified as a feasible, reliable, and valid measure for falls prediction in community dwelling older adults (11).

Statistical Analysis

Descriptive statistics for continuous and categorical variables were summarized as mean ± standard deviation and frequency and percentages, respectively. An independent samples t-test was used to test for significant differences in participant characteristics based on sex. Associations between the physical activity components and other covariates were assessed using Pearson correlations with statistical significance at $p < 0.05$.

Prior to statistical modeling, the residuals for all functional measures were assessed for normality using the Shapiro-Wilk's test. The 400W and UGS measures did not deviate from normality and thus the multiple linear regression method were used for these measures. However, the results of the Shapiro-Wilk's test indicated that 5xSTS and SPPB measures were not normally distributed. Thus, a natural-log transformation was applied to the 5xSTS measure and multiple linear regression method was used for this transformed measure. Back transformation (e^{β}) of the 5xSTS data was performed to present the geometric mean, standard error, and 95% confidence intervals. Data can be interpreted as a percent change in time to completion ($\beta*100$ per 30 minute change). The SPPB was dichotomized by scores of <10 (poor to moderate performers) and scores of 10+ (good performers) and a logistic regression statistic was used to analyze this measure.

Time spent in SB, LPA, MVPA, and total wear time was standardized by dividing the measured time spent in each of these activities by 60 $\text{min}\cdot\text{d}^{-1}$. Three different regression models were used to assess the relationship of SB and PA on function (single, partition, and substitution models). The single-variable model included only one activity variable (SB, LPA, or MVPA) per functional outcome to determine the overall association of each individual activity. The partition model included all activity variables (SB, LPA, and MVPA) into one model for each functional outcome variable to determine independent associations for each activity variable. The substitution model was used to estimate the relationship of substituting 60 $min \cdot d^{-1}$ of time spent in one activity with an equal amount of time spent in another activity with total wear time and the remaining activity being held constant. All models were adjusted for age and sex and a p-value criterion of 0.05 to determine statistical significance. Statistical reporting for the simple, partial, and substitution models include adjusted parameter estimates (β), standard errors (SE), and 95% confidence intervals (CI). All analysis was performed using SAS 9.4 (Cary, NC). For more information on how to perform isotemporal substitution modeling and its interpretation, refer to Mekary, Willett, Hu, & Ding 2009 (16).

To better simulate free-living scenarios, a separate isotemporal substitution model was performed for 60 $min \cdot day^{-1}$ using mixed redistributions of LPA and MVPA to replace SB. This was performed by redistributing 60 $min \cdot day^{-1}$ of SB toward a mixed share of the other two remaining activities (MVPA and LPA) by increments of 5 $min \cdot d^{-1}$ (i.e., 0 $min \cdot d^{-1}$ MVPA / 60 $min \cdot d^{-1}$ LPA; 5 $min \cdot d^{-1}$ MVPA / 55 $min \cdot d^{-1}$ LPA; 10 $min \cdot d^{-1}$ MVPA / 50 $min \cdot d^{-1}$ LPA; 15 $min \cdot d^{-1}$ MVPA / 45 $min \cdot d^{-1}$ LPA…60 $min \cdot d^{-1}$ MVPA/ 0 $min \cdot d^{-1}$ LPA) while keeping total wear time constant.

Cut-off points of meaningful change (minimal clinical important difference) for 400W and UGS determined based on the relationship between noticeable and beneficial change in perceived function with each specific performance-based measure (28). For 5xSTS, an improvement of 2.3 s is linked to a 49% improvement in self-reported function in vestibular disorders (29) and is represented by a 15.1% improvement completion time in the current sample. Clinical interpretation for SPPB was based on odds ratio of being a poor/moderate performer (< 10) compared to a good performer (≥ 10).

RESULTS

Descriptive Characteristics

Ninety-one individuals (60% female) completed the physical activity monitoring period and performed the physical function assessments. Descriptive results regarding the physical characteristics, PA monitoring, and physical performance tests can be found in Table 1. Approximately 93% of study participants were identified as white and 76% completed college-level education. Sixty-one percent of participants were overweight or obese and DXA imaging identified a significant sex difference in body composition. Other significant sex differences ($p < 0.05$) can be found in Table 1 and include height, weight, leg strength, accelerometer wear time, and steps·day^{-1}.

On average, participants wore the accelerometers for 13.99 ± 0.13 h·day^{-1} with female participants wearing the device significantly longer (30.7 min·d^{-1}, $p = 0.036$). Approximately 63.7% of valid wear time was spent in a SB, 33.4% in LPA, and 2.9% in MVPA with no sex differences. One in four participants met the recommended 150 min·wk^{-1} for MVPA (30).

Associations with Physical Function

Single and partition models. Single-activity, partition, and substitution model parameters are presented in Table 2. Single activity models identified LPA as a significant predictor of 400W ($\beta = 0.064$, 95% CI = 0.013-0.116, $p = 0.015$) and MVPA for 400W (0.407

0.219-0.595, $p < 0.001$), UGS (0.295, 0.146-0.444, $p = 0.0002$), 5xSTS (-4.433, -7.217 - -1.650, $p = 0.001$), and SPPB (3.233, 1.045-5.422, $p = 0.0038$). Lastly, total wear time was a significant predictor of 5xSTS performance (-0.747, -1.444 - -0.050, $p = 0.021$). Partition models presented similar associations for the physical performance measures relative to the single-variable models for activity, with an exception to total wear time.

Substitution models. Overall, substituting daily time spent in SB with either LPA or MVPA resulted in beneficial changes in physical function; however, the magnitude of improvements was greater for MVPA compared to LPA. Substitution models identified that replacing 60 $\text{min}\cdot\text{d}^{-1}$ of SB time with LPA resulted in a significant improvement in 400W (0.053, 0.000-0.106, $p = 0.0497$). However, a 60 $\text{min}\cdot\text{d}^{-1}$ increase in LPA alone did not lead to significant change the other three functional measures. When 60 $\text{min}\cdot\text{d}^{-1}$ of SB time was replaced by MVPA there was a significant improvement in 400W (0.385, 0.198-0.057, $p < .001$), UGS (0.293, 0.142-0.445, $p = 0.0002$), 5xSTS (-4.071, -6.855- -1.288, $p = .0024$), and SPPB (3.197, 0.953-5.442, $p = 0.0054$). All other variations of the activity substitution model can be found in Table 2. Not reported in the results is the output for 30 $\text{min}\cdot\text{d}^{-1}$ which provide the same statistical significance, but with parameter estimates of a lower magnitude.

Mixed redistribution-substitution models. The associations of mixed redistributions of time spent in LPA and MVPA to replace 60 $\text{min}\cdot\text{d}^{-1}$ of a SB on 400W, UGS, and 5xSTS can be found in Figure 1a-c and the odds ratios for SPPB in Table 3. In general, the redistribution of time spent in SB toward any mixture of LPA and MVPA tended toward improvements in all functional measures. Meanwhile, each 5 $\text{min}\cdot\text{d}^{-1}$ increase of MVPA as a representative proportion of total PA to replace 60 min·d^{-1} of SB resulted in greater magnitudes of improvement for all functional measures in a linear fashion.

Specifically, replacing 60 min·d^{-1} of SB with 60 min·d^{-1} of LPA and 0 min·d^{-1} in MVPA showed statistically significant and probable clinically meaningful changes in the 400W (0.053, 0.000-0.106, $p = 0.0497$). As shown in Figure 1a, each 5 min·d^{-1} increase in time spent in MVPA represented a linear greater magnitude of improvement in the 400W up to 60 min·d^{-1} of MVPA (0.385, 0.094 - 0.198, $p < 0.001$).

For UGS, redistributing 60 min·d^{-1} of SB time with as little as 5 min·d^{-1} of MVPA and 55 min·d^{-1} of LPA was resulted in a statistically significant improvement (0.047, 0.006-0.088, $p = 0.024$). As shown in Figure 1b, every 5 min·d^{-1} increase in MVPA represents a linear increase in magnitude of improvement up to 60 min·d^{-1} of MVPA (0.293, 0.142-0.444, $p < 0.001$).

For 5xSTS, redistributing 60 min·d^{-1} of SB toward 10 min·d^{-1} of MVPA and 50 min·d^{-1} of LPA resulted in a statistically significant improvement (-0.061, -0.109- -0.014, $p = 0.012$). As shown in Figure 1c, every 5 min·d^{-1} increase in MVPA represents a linear increase in magnitude of improvement up to 60 min·d^{-1} of MVPA (-0.260, -0.425- -0.095, $p = 0.002$).

For the SPPB, redistributing 60 min·d^{-1} of SB towards as little as 5 min·d^{-1} of MVPA and 55 min·d^{-1} of LPA was significantly associated with a 78% increased odds of falling into a good function range of 10-12 (1.785, 1.076-2.960, $p = 0.0247$). As shown in Table 3, increasing increments of daily time spent in MVPA represented significantly greater odds of having a score indicating good function with a full redistribution of SB toward 60 min·d^{-1} of MVPA resulting in a 25-fold increased odds (24.469, 2.594-230.781, $p = 0.0052$).

For all performance-based measures, there was a significant detrimental effect when replacing MVPA with any share of LPA or SB ($p < 0.01$).

DISCUSSION

Time spent in MVPA has been consistently linked to physical function while the contributions of LPA are not well established. Findings from this investigation highlight the importance of altering the LPA and SB balance with statistically significant improvements in 400W when replacing as little as 30 $\text{min}\cdot\text{d}^{-1}$ of SB with LPA. Doubling the LPA substitution to 60 $\text{min}\cdot\text{d}^{-1}$ was associated with a linear two-fold improvement in 400W resulting in a probable clinically meaningful change. Not all measures of physical performance were as sensitive as the 400W when replacing SB with isolated LPA. However, mixed ratios of time spent between LPA and MVPA to replace SB time may provide effective and feasible approaches to reducing SB time and improving physical function. Replacing 60 $\text{min}\cdot\text{d}^{-1}$ of SB with a 5-to-1 ratio of LPA-to-MVPA resulted in statistically significant improvements in the remaining performance-based measures. Furthermore, clinically meaningful changes in physical function required a mixture of LPA and MVPA in all physical performance measures, except for 400W when replacing 60 $\text{min}\cdot\text{d}^{-1}$ of LPA for SB.

These findings are important considering the growing public health concern of an aging older adult population with increased risk of mobility disability, the current SB and PA trends in older adults, and the scarcity of interventions targeting SB in older adults. Older adults accumulate the greatest amount of SB with age-related trajectories leading to reduced time spent in both LPA and MVPA (15). Physical activity presents the strongest overall evidence for combatting physiological decline and the accumulation of comorbidities that are linked with physical functioning (31). Further, these findings highlight the utility of creating flexible PA prescriptions that can use a mixture of various PA intensities while holding clinically relevant performance outcomes in mind. This may be of ultimate importance among an older adult population that lacks the musculoskeletal and cardiopulmonary capacity to perform continuous bouts of MVPA.

Reasons for the discrepancies between the effect of LPA on 400W and other physical performance measures may include the added cardiorespiratory challenge 400W compared to the other brief performance measures. While the SPPB score is predictive of the inability to complete the 400W (32), the 400W has been linked to premature mortality independent of SPPB scores (33) and predictive of medical conditions, falls, medication use, muscle strength, and muscle power among those that scored 10+ in the SPPB (34). The SPPB, UGS, and 5xSTS primarily consist of tasks that focus on balance and lower limb strength necessary to ambulate in brief bouts of < 30 s. In the current study sample, the average time for completing the 400W was approximately 9 min and 20 s with SPPB scores of 10+ performing nearly 2 min faster. These cross-sectional associations indicate that 400W performance may serve as a measure of interest to test the impact of LPA and MVPA to replace SB in moderate and high functioning older adults. Also, LPA may not be an adequate stimulus to preserve the rapid loss of function in late life as indicated by the brief measures, but may be an indicator of continuous ambulatory ability. However, the disability process which includes progressive declines in physical performance is predicted by the accumulation of multiple comorbidities which can be augmented by LPA and/or MVPA (4, 18, 35).

Traditional PA interventions that exclusively focus on increasing MVPA may fail to offset the negative health effects of SB which tends to replace LPA (36). Collectively, the independent health effects of SB and PA on physical function (5), morbidity and mortality (6), and the inability of PA interventions to offset SB time (37) suggest a need for concurrent prescription of SB, LPA, and MVPA. Systematic reviews have identified that SB is a relatively stable behavior that is not subject to change when increasing MVPA, but has the potential to be reduced when specifically targeted (37). Therefore, the transition of an *inactive couch potato* to an *active couch potato* (38) may disregard the potential confounding impact of SB on functional health.

The results from this study may aid the development of effective interventions aimed at reducing SB time and increasing PA time for the purpose of improving physical performance in older adults. The association between functional health and MVPA found in this study are consistent with previous findings using similar population representative surveillance data (5, 15), emphasizing the benefits of MVPA over LPA and SB. However, the complete transfer of an additional 30 or 60 $\text{min}\cdot\text{d}^{-1}$ of MVPA to replace SB may be impractical for many older adults. Specifically, the discretionary time available to older adults varies depending on socioeconomic status, occupation, and other social circumstances. Also, the heterogeneity in an individuals' preferences and ability to perform PA of various intensities are key determinants in the selection, initiation, and maintenance of PA as a form of lifestyle change (39). Thus, it is important to consider the impact of all levels of PA to maintain and rehabilitate functioning in older adults. Prolonged bouts of SB often take place in specific domains that may prove difficult to interrupt or replace including television viewing, computer use, and reading. Further, the initiation and successful maintenance of MVPA adoption in older adults has proven to be a formidable task while LPA has been identified as a preferred intensity (40). Therefore, the introduction of a LPA may be a practical and feasible approach to developing interventions to reduce SB.

To our knowledge, only one other study has used isotemporal substitution modeling to measure the association of reallocating SB with various PA intensities on measures of functional performance (17). Traditional multivariate regression models typically provide a regression coefficient per minute in a single activity while adjusting for time spent in activities that are inter-dependent and under the assumption of continuous time. Adjustment for time spent in other activities does not provide an appropriate control for a finite amount of time during waking hours with mutually exclusive activities. In addition to addressing these statistical limitations, the current technique has the advantage of addressing the potential underestimation of health benefits of PA and SB in previous studies by compounding the association of reducing time spent in an activity negatively associated with health and increasing time spent in an activity positively associated with health. While reporting the isotemporal substitution models in 60 $\text{min}\cdot\text{d}^{-1}$ increments provides immediately interpretable results, the jump to increasing LPA or MVPA by 60 $\text{min}\cdot\text{d}^{-1}$ may not be an immediately adoptable approach. As a possible introduction and not reported in our results is the output of a 30 $\text{min}\cdot\text{d}^{-1}$ isotemporal substitution model that reported the same statistical significance, but to lesser magnitude of change. Further strengthening this study is the use of dose-response mixed redistributions of LPA and MVPA to replace SB time. In addition to the strengths listed above, this study is not free of limitations. This study is limited by a relatively small sample size with fairly homogenous demographics. Additional studies and replication in larger and nationally representative samples would be important next steps to corroborate and further this study’s findings.

CONCLUSION

The health benefits of MVPA cannot be overstated, but how an individual spends the rest of the day spent between LPA and SB appears to play a role in determining physical function. Introducing LPA to specifically replace SB, but not MVPA, may serve as a sufficient stimulus to preserve and/or improve physical function in community-dwelling older adults. This emphasizes the need for public health approaches to mutually target SB, LPA, and MVPA when aiming to delay or reverse functional limitations in older adults. Previous investigations using this model have implied the use of doubling time spent in MVPA which may not be a feasible option for many older adults. The ability to mutually prescribe LPA and MVPA to augment clinically relevant changes in physical performance adds flexibility while optimizing interventions focused on clinically relevant changes in physical function.

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Figure Captions

Figure 1a-c: Figure 1-Substitution regression model for replacing SB with various ratios of LPA and MVPA (0-60 min). For 400W and UGS, values indicate the parameter estimate and 95% confidence intervals adjusted for age and sex. 5xSTS is presented as the geometric mean and 95% confidence intervals and should be interpreted as a percent change in 5xSTS completion time per 60 minute substitution for SB. Reference values for minimum clinically important difference represented by black dashed line: 400W at 0.05-0.075 $m \cdot s^{-1}$ (20); UGS at 0.03-0.05 $m \cdot s^{-1}$ (20). 5xSTS at 15.1% based on an MCID of 2.3 s (25).

400W: 400-meter walk, UGS: usual gait speed, 5xSTS: timed five-time sit-to-stand, SB: sedentary behavior, LPA: light-intensity physical activity, MVPA: moderate-to-vigorous-intensity physical activity, OR: odds ratio

TABLE 1. Descriptive Characteristics

	Total (N=91)		Female (n=55)		Male (n=36)		
	Mean	SD	Mean	SD	Mean	SD	P $_{sex}$
Age (y)	70.7	10.2	69.4	10.8	72.8	8.6	.271
Height (cm)	166.6	9.1	162.4	7.4	173.7	7.2	<.00
Body mass (kg)	75.6	17.4	71.7	16.9	82.1	16.3	.002
Body mass index kg·m^2-1	27.2	5.7	27.2	6.2	27.2	4.8	.929
400W (m·s^{-1})	1.4	0.3	1.4	0.3	1.4	0.4	.752
UGS (m·s^{-1})	1.1	0.3	1.1	0.3	1.1	0.2	.772
5xSTS (s)	15.2	4.8	15.2	4.3	15.3	5.5	.957
SPPB balance score (0-4)	3.8	0.5	3.7	0.6	3.9	0.3	.063
SPPB chair score (0-4)	2.2	1.1	2.1	1.1	2.2	1.1	.715
SPPB gait score (0-4)	3.8	0.6	3.8	0.7	3.9	0.4	.430
SPPB total score (0-12)	9.8	1.6	9.7	1.7	9.9	1.4	.354
Total Wear Time (min·d^{-1})	844.8	75.8	856.3	67.0	825.6	86.3	.036
SB (min·d^{-1})	536.6	75.7	539.5	63.7	531.8	93.2	.468
LPA (min·d^{-1})	283.1	73.3	290.9	67.1	270.1	82.0	.138
MVPA (min·d^{-1})	25.0	20.9	25.8	22.4	23.7	18.2	.912
Steps (steps·d^{-1})	6343	3950	7229	3486	4858	4279	.036
Time spent in SB (% wear time)	63.7	8.2	63.2	7.3	64.6	9.5	.595
Time spent in LPA (% wear time)	33.4	7.6	33.8	6.9	32.6	8.6	.434
Time spent in MVPA (% wear	2.9	2.4	3.0	2.5	2.9	2.1	.626
≥10min MVPA bout (min·d^{-1})	13.8	16.5	15.3	18.5	11.2	12.4	.593
≥20min SB bout (min·d^{-1})	212.9	71.8	206.7	61.5	223.3	86.4	.306
≥150 min·d^{-1} of MVPA (% of participants)	25.3	43.7	31.6	46.9	14.7	35.9	.187

400W: 400-meter walk, 5xSTS: timed five-time sit-to-stand, UGS: usual gait speed, SPPB: short physical performance battery, SB: sedentary behavior (<100 counts·min^{-1}), LPA: light-intensity physical activity (100-1951 counts·min^{-1}), MVPA: moderate-to-vigorous-intensity physical activity (≥1952 counts·min^{-1}), SD: standard deviation. Accelerometer total wear time based on Choi Algorithm (22) and logs.

TABLE 2. Single, partition and substitution model estimates for SB, LPA, MVPA, and Total Wear Time in 60 minute increments

	SB (60 min)				LPA (60 min)				MVPA (60 min)				Total Wear Time (60 min)			
Analysis Method	β	SE	Lower 95% CI	Upper 95% CI	β	SE	Lower 95% CI	Upper 95% CI	β	SE	Lower 95% CI	Upper 95% CI	β	SE	Lower 95% CI	Upper 95% CI
400W (m·s⁻¹)																
Substitution of activity to replace SB	Dropped				**0.053**	**0.027**	**0.000**	**0.106**	**0.385**	**0.094**	**0.198**	**0.57**	0.003	0.025	-0.047	0.053
Substitution of activity to replace LPA	**-0.053**	**0.027**	**-0.106**	**0.000**	Dropped				**0.332**	**0.098**	**0.136**	**0.528**	**0.056**	**0.028**	**0.002**	**0.111**
Substitution of activity to replace MPVA	**-0.385**	**0.094**	**-0.572**	**-0.198**	**-0.332**	**0.098**	**-0.528**	**-0.136**	Dropped				**0.388**	**0.094**	**0.200**	**0.575**
Partition Models	0.003	0.025	-0.047	0.053	**0.056**	**0.028**	**0.002**	**0.111**	**0.388**	**0.094**	**0.200**	**0.575**	N/A			
Single Activity Models	-0.075	0.024	-0.085	0.010	**0.064**	**0.026**	**0.013**	**0.116**	**0.407**	**0.095**	**0.219**	**0.595**	0.041	0.0025	-0.009	0.090
UGS (m·s⁻¹)																
Substitution of activity to replace SB	Dropped				0.025	0.021	-0.018	0.068	**0.293**	**0.076**	**0.142**	**0.445**	-0.008	0.021	-0.050	0.033
Substitution of activity to replace LPA	-0.025	0.021	-0.068	0.018	Dropped				**0.269**	**0.080**	**0.112**	**0.426**	0.016	0.022	-0.027	0.060
Substitution of activity to replace MPVA	**-0.293**	**0.076**	**-0.445**	**-0.142**	**-0.269**	**0.080**	**-0.426**	**-0.112**	Dropped				**0.285**	**0.076**	**0.133**	**0.436**
Partition Models	-0.009	0.035	-0.050	0.032	0.016	0.021	-0.027	0.060	**0.285**	**0.076**	**0.133**	**0.436**	N/A			
Single Activity Models	-0.027	0.019	-0.065	0.011	0.026	0.020	-0.014	0.066	**0.295**	**0.075**	**0.146**	**0.444**	0.013	0.020	-0.026	0.052
5xSTS (% change s) [a]																
Substitution of activity to replace SB	Dropped				-0.334	0.392	-0.1.115	0..446	**-4.071**	**1.400**	**-6.855**	**-1.288**	-0.454	0.383	-1.215	0.308
Substitution of activity to replace LPA	0.334	0.392	-0.446	1.115	Dropped				**-3.737**	**1.454**	**-6.630**	**-0.844**	**-0.788**	**0.403**	**-1.590**	**0.013**
Substitution of activity to replace MPVA	**4.071**	**1.400**	**1.288**	**6.855**	**3.737**	**1.454**	**0.844**	**6.630**	Dropped				**-4.525**	**1.403**	**-7.316**	**-1.734**
Partition Models	-0.454	0.383	-1.215	0.308	-0.788	0.403	-1.590	0.013	**-4.525**	**1.403**	**-7.316**	**-1.734**	N/A			
Single Activity Models	0.092	0.349	-0.602	0.786	-0.622	0.365	-1.349	0.104	**-4.433**	**1.400**	**-7.217**	**-1.650**	**-0.747**	**0.350**	**-1.444**	**-0.050**
SPPB (score: <10 or 10+) [b]																
Substitution of activity to replace SB	Dropped				0.342	0.260	-0.168	0.851	**3.197**	**1.145**	**0.953**	**5.442**	0.188	0.231	-0.264	0.641
Substitution of activity to replace LPA	-0.342	0.260	-0.851	0.168	Dropped				**2.856**	**1.170**	**0.562**	**5.150**	0.530	0.276	-0.012	0.1.071
Substitution of activity to replace MPVA	**-3.197**	**1.145**	**-5.442**	**-0.953**	**-2.856**	**1.170**	**-5.150**	**-0.562**	Dropped				**3.386**	**1.179**	**1.074**	**5.697**
Partition Models	0.188	0.231	-0.264	0.641	0.530	0.276	-0.012	1.071	**3.390**	**1.179**	**1.074**	**5.697**	NA			
Single Activity Models	-0.152	0.193	-0.530	0.226	0.430	0.227	-0.015	0.876	**3.233**	**0.1.117**	**1.045**	**5.422**	0.335	0.203	-0.062	0.733

400W: 400-meter walk, UGS: usual gait speed, 5xSTS: timed five-time sit-to-stand, SPPB: short physical performance battery, SB: sedentary behavior, LPA: light-intensity physical activity, MVPA: moderate-to-vigorous-intensity physical activity, β: regression coefficient, SE: standard error

[a] Statistical analysis for 5xSTS was performed after a natural log transformation. A back transformation (e^{β}) was performed to obtain the geometric mean presented in the table.

[b] Estimates for the SPPB single, partition, and substitution models were performed using logistic regression to model the log odds ratio of good performers vs poor/moderate. To obtain the odds ratio, the regression coefficient should be exponentiated.

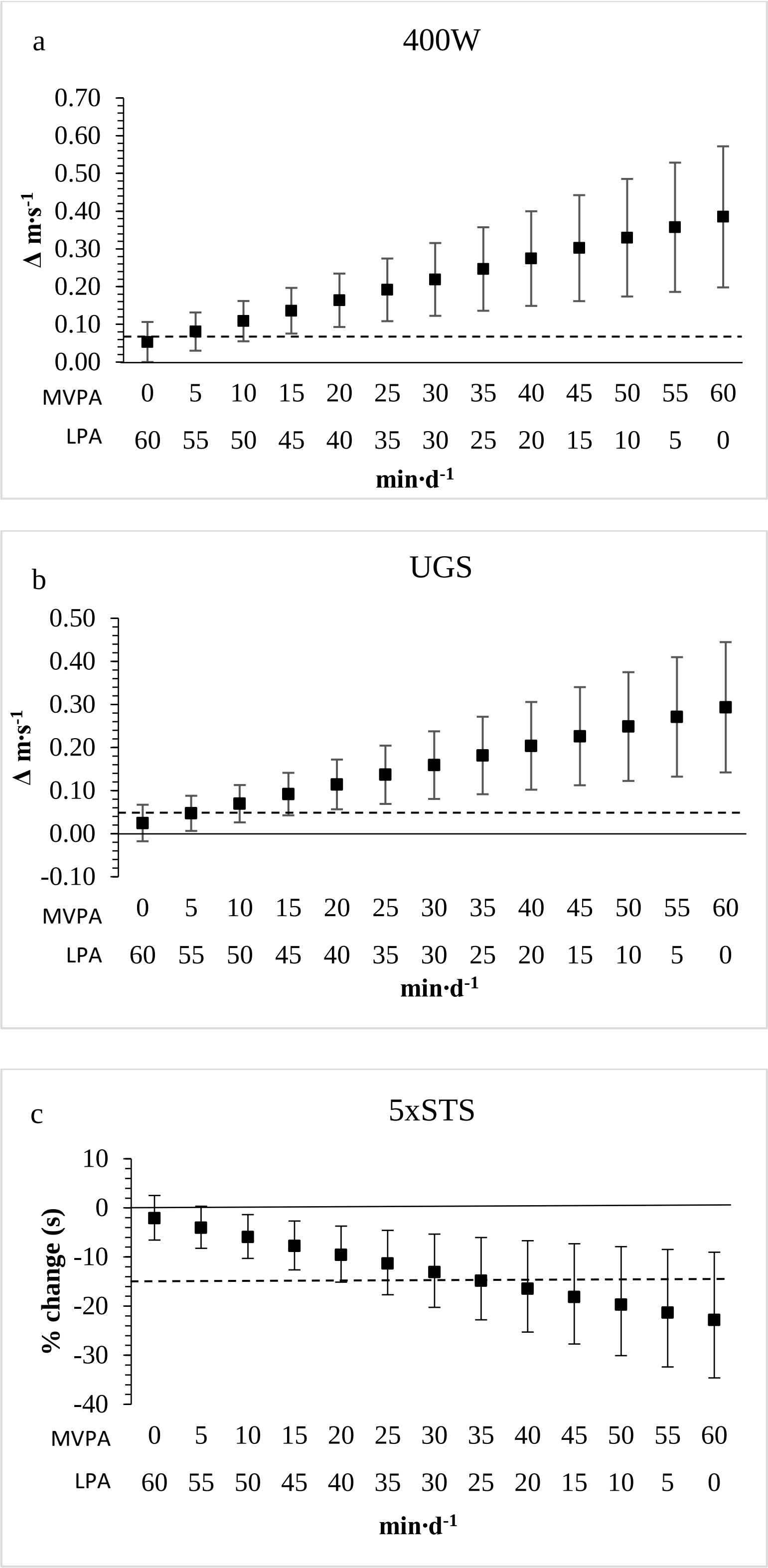
All models are adjusted for age and sex. Values tagged in bold are statistically significant ($p < 0.05$).

TABLE 3. Odds ratio of changing from an SPPB score of low/moderate (<10) to good (10+)

Substituting 60 min·d^{-1} of SB for:					
LPA (min)	MVPA (min)	OR	Lower 95%	Upper 95%	P
60	0	1.4070	0.8454	2.3418	0.1890
55	5	1.7849	1.0765	2.9595	0.0247
50	10	2.2649	1.2808	4.0052	0.0049
45	15	2.8732	1.4505	5.6915	0.0025
40	20	3.6449	1.5955	8.3267	0.0022
35	25	4.6252	1.7264	12.3912	0.0023
30	30	5.8675	1.8498	18.6113	0.0027
25	35	7.4434	1.9701	28.1224	0.0031
20	40	9.4443	2.0900	42.6774	0.0035
15	45	11.9821	2.2114	64.9229	0.0040
10	50	15.2003	2.3352	98.9395	0.0044
5	55	19.2883	2.4627	151.0662	0.0048
0	60	24.4688	2.5943	230.7811	0.0052

SPPB: short physical performance battery, SB: sedentary behavior, LPA: light-intensity physical activity, MVPA: moderate-to-vigorous-intensity physical activity, OR: odds ratio

Figure 1


a
400W
Δ m·s⁻¹
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
MVPA
0 5 10 15 20 25 30 35 40 45 50 55 60
LPA
60 55 50 45 40 35 30 25 20 15 10 5 0
min·d⁻¹
b
UGS
Δ m·s⁻¹
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
MVPA
0 5 10 15 20 25 30 35 40 45 50 55 60
LPA
60 55 50 45 40 35 30 25 20 15 10 5 0
min·d⁻¹
c
5xSTS
% change (s)
10
0
-10
-20
-30
-40
MVPA
0 5 10 15 20 25 30 35 40 45 50 55 60
LPA
60 55 50 45 40 35 30 25 20 15 10 5 0
min·d⁻¹

CHAPTER IV: PILOTING THE ACCEPTANCE AND FEASIBILITY OF USING A SEATED ELLIPTICAL DURING SEDENTARY BEHAVIORS IN OLDER ADULTS

Nicholas L. Lerma, Chi C. Cho, Ann M. Swartz, Young Cho, & Scott J. Strath

ABSTRACT

INTRODUCTION: Older adults aged 60+ years are particularly vulnerable to the exposure and negative health consequences related to sedentary behavior (SB). The development of feasible and effective SB interventions in older adults is needed. The purpose of this study is to explore the feasibility and acceptability of a seated elliptical device (SED) to introduce a light-intensity PA to sedentary activities in the homes of older adults. METHODS: Each participant was outfitted with hip-mounted activity monitor and SED in the home for seven days. Participants were randomly assigned to one of four pedaling duration groups (15, 30, 45, and 60 minutes/day) and instructed to accumulate SED pedaling at a self-selected light-intensity during typical SB activities for a minimum of three out of seven days. Pedaling adherence, participant perceptions, and SB displacement were assessed. RESULTS: There was a significant linear group trend ($p<.001$) for minutes pedaled per day and 100% adherence across all four pedaling duration groups with no significant difference in total pedaling days completed ($p=.241$). The 45 and 60 min group accumulated greater minutes per day of pedaling than the 15 and 30 min groups ($p<.005$) with no significant differences between the 45 and 60 min groups or the 15 and 30 min groups. Participants' perceptions of using the SED were positive overall. CONCLUSION: Older adults were just as likely to complete 60 minutes of daily pedaling as all other groups without interrupting their typical sedentary activity. Longer-term adherence of the SED and the impact of replacing SB with a seated LPA on geriatric-relevant health outcomes should be investigated.

INTRODUCTION

Sedentary behavior (SB) is a growing public health concern with recent epidemiological and prospective studies linking elevated daily SB to poor health and all-cause mortality, independent of time spent in moderate-to-vigorous-intensity physical activity (MVPA) (Healy et al., 2008; Katzmarzyk et al., 2009; Kim et al., 2013; Matthews et al., 2012; Owen et al., 2011; Warren et al., 2010). Older adults are particularly susceptible to SB and vulnerable to its ill-health effects with population-based studies reporting that older adults may accumulate up to 70-80% of their waking hours in sedentary pursuits (Harvey et al., 2015; Healy et al., 2011, Matthews et al., 2008). Importantly, emerging evidence suggests patterns of how SB is accumulated throughout the day may be more telling than total SB time with longer bouts of SB linked to poorer outcomes (Dunstan et al., 2012; Healy et al., 2008; Healy et al., 2011, Owen et al 2010).

Public health officials and scientists are searching for effective and acceptable interventions to reduce SB by interrupting or replacing/reducing seated or lying activities to increase daily energy expenditure. While the context of SB among young and middle-aged adults primarily occurs in the workplace, time spent in SB in older adults typically occurs in the home while watching television, performing computer tasks, and reading (Gardner et al. 2016). A recent dose response meta-analysis for SB identified a threshold of 6-8h/day of total sitting and 3-4h/day of TV viewing where the risk for all-cause mortality and cardiovascular disease is significantly increased (Patterson et al. 2018). A review by Gardner and colleagues (2016) identified that restructuring of the social and physical environment around SB presented the most promising approach to reducing SB time. Therefore, future interventions targeting the reduction of SB should focus on incorporating effective SB interruptions that are convenient, easy, and naturally prompted.

A seated elliptical device (SED) has been identified as an effective option of increasing the energy expenditure during typical seated activities in various age groups (Carr et al., 2014, Rovniak et al., 2014, Lerma et al 2017) and may serve as a practical method to purposefully replace SB with LPA. The prior investigation using this device in older adults is limited to lab-based efficacy studies performed across short durations of SB activities. The ability of older adults to accumulate pedaling times up to durations considered clinically meaningful are not established. Therefore, the primary aim of this study is to compare different SED daily pedaling time interventions (15, 30, 45, and 60 minutes/day) in a one week efficacy trial in the homes of older adults. A secondary aim is to examine the acceptability and feasibility of using the SED in the homes of older adults to increase daily LPA.

METHODS

Participants

Twenty able-bodied, healthy, community-dwelling older adults were recruited to participate in this pilot study. Participants were recruited by posting flyers in the local community and university, the laboratory web page, and through a research participant registry. Inclusion criteria for this study required participants to be at least 60 years of age, able to perform a light-intensity pedaling activity, spend at least 4 hours of their day seated while watching television, performing computer tasks, or reading, not have any current lower limb orthopedic conditions that would prevent the ability to pedal comfortably, have not had any cardiovascular disease event in the past 12 months such as a stroke, angioplasty, or bypass surgery. Potential participants were excluded if they could not complete the full 7-day trial.

Ethical approval was received by the university Institutional Review Board and each participant provided written informed consent prior to participating in the study.

After determining eligibility to participate, the sample of 20 was randomized into four groups of five, each group receiving different SED interventions, based on the duration of the pedaling activity: 15 min/day, 30 min/day, 45 min/day, and 60 min/day. Participants were randomized into groups using a predetermined block randomization schedule that included blocks of 4.

Study Overview

This home-based pilot study was designed to assess the feasibility and acceptability of older adults to accumulate various daily durations of light-intensity pedaling using the SED in the homes of older adults. Figure 1 illustrates the study timeline. A research team member made in-home visits to the residence of the community-dwelling older adult participants to collect anthropometric, demographic, health history, self-reported SB and physical activity (PA) data. During the in-home visit, the research team member described the hazards of SB, outcome expectations of LPA, and introduced the SED (Stamina, In-Motion, Springfield, MO) to the older adult. The SED was placed in a seated context that was personally identified as a *hotspot* for SB in the home. The research team member was not blinded to group allocation during in-home visits, but followed a script of prepared responses if the participant inquired about ability to perform accumulated bouts of pedaling.

Trial Pedaling Period

Over the course of the seven days that the SED was in the home, the participants were instructed to pedal at least three of the next seven days using the SED at a self-selected pace while in the predetermined seated context to accumulate a minimum duration of 15 min/day, 30 min/day, 45 min/day, or 60 min/day depending on group assignment. The participants were instructed that they could accumulate several brief pedaling bouts of at least two minutes in length to work towards their group-based total daily goal for pedaling minutes. Each pedaling bout was recorded on a daily log sheet to help participants track the multiple bouts performed on a single day. The participant was instructed that no other individual in the home was to use the device to avoid contamination of the data measurements.

Under the pedal of the SED, an accelerometer (Actigraph GT3X+) was used to identify the frequency, intensity, and duration that the participant used the SED. The device-mounted accelerometer provided objective measurement of the adherence to the group-based daily pedaling goals using the SED. Each pedaling group received a 5% window to meet their daily pedaling goal to adjust for display-time lag on the SED monitor. For example, if an individual pedaled 58 minutes on three days, this would be identified as 100% adherence since the accumulated pedal time is within the 5% window of 60 minutes.

The participants were further outfitted with a body-worn accelerometer (Actigraph GT3X+) to gather individual objective measures of SB and PA. Participants were instructed on how to properly place the device and given a document with instructions for reapplication and personal wear logs. Specifics regarding the body worn device are later described.

At the end of the 7-day trial period, the research team member returned to the home of the older adult to collect monitor wear logs, SED use logs, SED, the device- and body-worn accelerometers, and post-test questionnaires.

Measures

Participant descriptive characteristics

Basic demographic and anthropometric data were collected prior to testing. Participant demographics were collected using a health history questionnaire. Standard procedures were performed to collect height (nearest 0.1 cm) and weight (nearest 0.01 kg) in the homes while using a portable scale and tape measure (Ferguson, 2014).

Sedentary behavior

Self-reported measurement. The Measure of Older Adults Sedentary Time (MOST) was included to provide a context for objective monitoring of SB. The 7-day recall instrument was completed after the 7-day trial period. Participants were asked to recall time spent in specific sedentary activities in the previous seven days and report as total hours in a week. Activities include TV viewing, computer use, reading, socializing, transport, hobbies, and other sedentary time. Duration of hours in each activity is provided and summed durations of each activity provide total self-report SB time. The MOST has been identified as valid and reliable self-report instruments for SB in older adults (Gardiner et al 2011).

Objective measurement. The Actigraph GT3X+ (ActiGraph, LLC, Pensacola, FL) was used as a body-worn device for the measurement of PA and SB. The Actigraph GT3X+ uses three internal accelerometers to measure tri-axial changes in human movement which were stored at a sampling rate of 100Hz. Participants were instructed to wear the PA monitor for the seven day monitoring period between the two home visits and fill out a daily wear time log for when the device was placed on and removed. The Actigraph GT3X+ was instructed to be worn on the right hip during all waking hours and only to be removed during water activities or sleep. The Actigraph data was downloaded using the Actilife software version 6.13.3 with a 60-second epoch length and an algorithm applied to determine valid wear-time (Choi et al 2011) which was supplemented by self-report monitor wear logs. Count per minute (CPM) cut-points were used to identify time spent in various intensities of PA (SB: < 100 CPM, LPA: 100-1951 CPM, MVPA: ≥1952 CPM) (Matthew 2005; Freedson, Melanson, & Sirard, 2008). While there is not consensus on Actigraph CPM cut-points for older adults, these cut-points are the most widely used in the older adult population. Further, while the Actigraph GT3X+ is not designed to identify body posture when placed at the hip-location, inactivity as identified by low activity counts (<100 CPM) will be operationalized to SB. A wear time ≥ 10 hours/day was used as a criterion for a valid day and ≥ 5 days of wear time as a criterion for a valid 7-day monitoring period (Sasaki et al 2017). The Actigraph GT3X+ has been identified as valid and reliable measures of SB and PA (Matthews et al., 2008, Schrack et al., 2016).

Seated elliptical device

Self-reported measurement of adherence. Participants were provided a daily use log to provide time of day the SED was used and duration of use. The participant was instructed to complete this each time they used the device and sum the durations of use at the end of the day.

Objective measurement of adherence. An Actigraph GT3X+ accelerometer was used to measure the use of the SED in the home. Specifically, the accelerometer was securely placed underneath the right-sided foot pedal of the SED with a wrist-strap. The accelerometer was able to travel unimpeded along with the foot pedal along every revolution. The accelerometer was set to collection rate of 30 Hz and the data from the accelerometer was extracted and analyzed following seven days of monitoring. Information regarding frequency, duration, and length of SED used was determined using a timestamped spreadsheet of accelerations to confirm adherence to the group-based recommended pedaling goals.Additionally, the accelerometer was able to provide an estimated intensity of the pedaling bouts based on measured revolutions per minute (RPM) with no added resistance.

Perceptions of use. After using the SED in the home for one week, participants completed modified participant experience questionnaire (PEQ) that was developed using a technology acceptance model approach (Mercer et al 2016). Specifically, the questionnaire addressed perceived usefulness, perceived ease of use, attitude toward using, behavior intention to use, device use, perceptions toward the goals, and external variables.

Statistical analysis

Daily pedaling durations were determined using one second summary data from the raw SED-mounted accelerometer data. This data was used to determine SED patterns of use and to cross-reference with body-worn activity monitors that relied on one minute epoch summarized data. Pedaling patterns as determined by accelerometry include pedaling bout duration, pedaling bouts per day, daily pedaling duration, and total weekly pedaling. Revolutions per minute (RPM) of pedaling was determined using R: Foundation for Statistical Computing version 3.4.1 (Vienna, Austria) to count each change in g (gravitational force) in the y-axis of the raw accelerometer data from -.05 to .05, or .05 to -.05, as a half revolution.

All statistical analyses were performed using SPSS 24.0 (IBM, Chicago, IL). Descriptive statistics for participant demographic, anthropometric, activity monitor, and pedaling variables were performed and all variables were tested for normality by examining frequency distributions prior to analysis. Residuals were tested for normality using a Shapiro-Wilk test. A Fisher’s exact test was performed to determine whether the groups are different and if linear trends existed in the daily adherence to pedaling goals. A one-way ANOVA was performed to test for linear group trends for average daily pedaling duration across groups with various pedaling time prescriptions. A positive linear trend for pedaling durations across groups would indicate that study participants were successfully able to increase pedaling duration based on prescribe pedaling doses.

Cohen's d was used to determine effect sizes for changes in daily SB and LPA on pedaling days. Specifically, individual pedal day SB as determined by the hip-worn accelerometer were subtracted by accumulated pedaling minutes as determined by the SED mounted accelerometer. This provided an "adjusted SB" by cross-referencing the accelerometer data. Likewise, pedal day LPA was transformed to "adjusted LPA" by adding daily SED pedaling minutes to daily LPA. Adjusted SB and LPA values were then summarized by groups and compared to unadjusted values of SB and LPA to determine effect sizes.

Participant characteristics and SED pedaling data are presented as mean ± SD. A Bonferroni adjustment was used for group comparisons.

RESULTS

Participant characteristics

Twenty older adults (mean ± SD) 71.9 ± 5.25 years, including 11 males and 9 females, participated in this one week pilot study to evaluate the feasibility and acceptability of pedaling of accumulating up to 60 minutes per day of pedaling. According to the trial period hip-accelerometer, on average, study participants spent approximately 69% of their waking hours in SB, 28% in LPA, and 3% in MVPA. See Table 1 for participant characteristics.

A MOST questionnaire provided a context of the accelerometer-derived 593.2 minutes per day of SB, with over one-third of SB time spent watching television or videos (37%), followed by computer use (19%), social activities (11%), reading (10%), transportation (9%), unlisted activities (8%), and hobbies (6%). Five of the 20 participants met or exceeded the MVPA recommendations (PAGAC, 2008) during the trial period based on accelerometry.

Seated elliptical adherence

Both accelerometer-derived measurements and self-reported pedaling logs were used to assess SED adherence. Self-reported daily pedaling duration using a daily pedaling log was significantly correlated with daily pedaling duration by accelerometry (r=0.987). A Bland-Altman plot (data not shown) was used to indicate mean differences between self-reported and accelerometer-derived daily pedaling durations with a mean bias of 0.156 min per day greater pedaling when using the self-reported pedaling logs. The dispersion of the differences were considerably narrow with limits of agreement of -6.30 and 6.61 min, highlighting that there was good agreement between self-reported SED use and measured SED use.

There was a significant positive linear trend for average minutes pedaled across study groups (F=53.729, p<.001), as seen in Table 2. Both the 45 and 60 min pedaling groups pedaled significantly longer than the 15 min (p<0.001) and 30 min groups (p=0.002) with no significant difference between 45 and 60 minute groups (p=1.00) and no significant difference between the 15 and 30 min groups (p=.296). Further, there was 100% adherence to completing pedaling duration goals for a minimum 3 days per week in all four pedaling groups with no significant difference for pedaling days completed between groups (p=1.00). The average number of pedaling bouts per day increased with greater daily prescribed pedaling durations, but this trend not statistically significant (p=.169) and there were no statistically significant differences in average pedaling RPM between groups (p=.457)

The effect sizes for changes for daily SB can be seen in Table 3. These data were analyzed by cross-referencing hip and SED-mounted accelerometer data from the participants' pedaling days only. Pedal and non-pedal day comparisons were not performed because seven of the participants did not have a non-pedal day. For pedal days, an adjusted SB was determined by substituting hip accelerometer SB time with LPA time based on respective daily pedaling durations determined by SED mounted accelerometry. Similarly, adjusted LPA time on pedal days was determined by adding LPA based on respective daily pedaling durations to hip accelerometer LPA time. Values for pedal-time adjusted daily SB and PA and effect size can be found in Table 3. A linear group trend for daily SB on pedal days was not statistically significant, but did approach significance (p = 0.075). However, the 60 min group averaged approximately an hour less SB than the 30 and 45 min groups. Comparisons between unadjusted and adjusted pedal day values for SB and LPA were used to determine the effect size for reducing SB and/or increasing LPA with a Cohen's d. On average, the 15, 30, 45, and 60 min groups experienced a 4.3%, 5.4%, 10.6%, and 11.3% reduction in SB on pedal days, respectively. Concurrent changes in pedal day activity for the 15, 30, 45, and 60 min groups included an 8.3%, 16.0%, and 29.1%, and 23.6% increase in LPA, respectively. See Figure 2 for absolute and relative changes in SB and LPA for the 60 minute pedaling group.

Self-report pedaling perceptions

Overall perceptions toward the SED were positive with no statistical differences reported between groups. In particular, study participants provided positive comments for ease of use and comfort when introducing this pedaling device to their daily living patterns. Notable positive responses to the pedaling device and prescription included "Good for bad weather days", "It gave me a feeling of accomplishment while watching TV", "Made it easy to move; i.e., easy to add movement to my daily routine", "Pedaling-seems to improve circulation and strengthen my legs", and "Easy to use & did not interfere with some activities". Negative responses to the pedaling device and prescription included "The digital screen is too small", "Uncomfortable for my feet", "Would like to do more upper body exercise", and "Would like to have tried harder pedaling". A complete list of responses can be found in Table 4.

DISCUSSION

This pilot study supports the ability, acceptability, and feasibility of a SED to interrupt and/or replace SB with LPA in the homes of older adults. Primary findings indicate that daily pedaling time significantly increased based on the randomized pedaling duration group assignment with all four groups meeting 100% adherence to the *a priori* prescribed minimum of 3 of the 7 days. Further, most participants viewed the SED as an easy, convenient, and effective way to introduce PA to their daily routine without interrupting the underlying sedentary activity being performed.

No differences existed in the ability to replace 15 to 60 minutes of SB with seated light-intensity pedaling in the homes of older adults. Cross-sectional findings suggest replacing SB with 60 minutes per day of LPA is associated to clinically meaningful changes in geriatric-relevant health outcomes, such as cardiometabolic health, physical function, cognitive function, quality of life, and mortality (Buman et al., 2010; Chastin et al., 2015, Lerma et al., 2017, Wijndaele et al. 2017). Prior to this trial it was unclear whether introducing 60 minutes per day of seated light-intensity pedaling would be a feasible and acceptable approach to reduce SB. Previous studies have shown the capability to reduce daily sedentary time by up to 90 minutes when directly targeting SB, but most of these studies did not include older adults nor a novel pedaling motion (Martin et al 2015, Prince et al 2014). A review by Copeland et al (2017) concluded it may be feasible to reduce SB time in older adults with SB interventions, but there was insufficient evidence to draw conclusions about the effectiveness of these interventions on reducing SB time and their impact on geriatric-relevant health outcomes. The individual pedaling patterns of participants in the current study suggest interrupting SB with 60 minutes per day of LPA is feasible. Interestingly, the participants in this study were given the opportunity to exceed the minimum daily goal, yet most tended to focus on completing their groups' respective minimum daily minutes. However, more than two-thirds of the study participants exceeded the minimum prescribed days of pedaling. These findings are optimistic that introducing the SED into daily routines can be performed without obstruction, but increasing amounts of daily pedaling time may require further behavioral support strategies including time management and/or motivation.

Secondary outcomes of this study identified positive perceptions to using the SED during SB activities in the home. The development of feasible and acceptable methods to reduce SB time in older adults are necessary to achieve long-term adherence. Historically, health promotion interventions have struggled with long-term adherence following intervention periods (Middleton, Anton, & Perri, 2013). A recent meta-analysis for non-occupational SB interventions in adults identified success in reducing leisure sitting time in the medium term by 30 minutes and TV viewing in the short and medium term by 61 minutes and 11 minutes, respectively (Shrestha et al, 2018). Further findings from the meta-analysis identified no significant pooled effects in the long term, no evidence to support the effectiveness of SB interventions in older adults, and limited reporting on the participants' perceptions toward the behavioral change implementation. Typical SB intervention strategies include restricting certain SB activities, sitting less, or adding PA without accounting for the reallocation of time-use during waking hours. These types of interventions may be prone to resistance due to the invasive nature of altering behaviorally embedded daily activities. For example, a timed notification to stand up and walk may interrupt the enjoyment or process of the underlying activity. In contrast, the participants in the current study were allowed to maintain time spent in their seated leisure activities while increasing their daily LPA by up to 64 minutes per day. Perceived usefulness and ease of use are two key beliefs from the technology acceptance model that explain participant variance in the acceptance and adoption to new and old technologies, both of which scored positively in this pilot trial. By altering the physical environment with a SED in their most frequented seated position, the participants reported the ability to maintain their typical pedaling activities without sacrificing the enjoyment of their typical daily activities. Assessment of participant perceptions should be measured for longer periods of time to determine if there is a drop off due to a novelty effect.

However, these findings do highlight the potential for inclusion of the device in long-term intervention trials.

A major strength of this study was the use of evidence-based practices in an older adult sample. Most of the scientific literature on SB interventions have focused on younger adults in the workplace with limited reporting on effective practices to reduce daily SB in older adults. Older adults are at the greatest risk for accumulating time spent in SB (Harvey et al., 2013) and experience greater magnitudes of poor health effects relative to time spent in SB (Dogra & Stathokostas, 2012). Best practices to reporting were followed to improve the current understanding of SB in older adults. The dose and type of SB is becoming increasingly important with particular SB contexts linked to worse health outcomes and possibly requiring different mode of intervention. Therefore, reporting the context and time distribution of SB activities may be of importance. Further, this study took precaution to encourage participants to only use this device during seated leisure activities and to avoid the replacement of other PA. This was of particular importance considering the risk for negative health consequences when replacing a higher intensity PA with LPA (Buman et al. 2010, Chastin et al. 2016, Lerma et al. 2017). Meta-analysis of SB interventions in adults and older adults identified that the reallocation of SB to time use in other pursuits including sleep, standing, LPA, or MVPA are not typically accounted for. Lastly, this study measured and reported participant perceptions toward the intervention and device which is under-reported in the literature and may provide clues into the potential for the adoption and adherence to SB and PA change.

This pilot investigation also had some key limitations. The study consisted of a small sample size and only lasted seven days. However, this study served as a pilot study to determine best practices for a randomized control trial to explore the feasibility and acceptability of a novel pedaling device. The *a priori* determined minimum of three pedaling days in the one week trial is considerably less than the standard practice of meeting an 80% adherence rate to measure success in exercise interventions, which would have been achieving pedaling goals on 6 out of the 7 days in the current intervention. While a 60 minute per day reduction in SB was a clinically relevant target, we were concerned that 60 minutes per day of pedaling for seven consecutive days may have been too physically demanding in older adults that may have been physically inactive. With the expectation of mild muscle and joint soreness from a possibly unfamiliar movement we chose to allow for rest days between pedaling days. Also, we aimed to take into account life events, providing the participants the opportunity to self-select three days that they could accumulate their pedaling time goals. Noted in the participants' perceptions, not all participants experienced equal satisfaction of using the pedaling device. In particular, perceptions toward using the device appeared to be influenced by chair type, device positioning and location, body size, current level of functioning, and understanding of the potential benefits.

CONCLUSION

In conclusion, a SED was effective at reducing the time spent in SB and increasing LPA in the homes of older adults. Importantly, the topographical introduction of this device did not interrupt or reduce the enjoyment of typical underlying daily activities and behaviors. Also, while this device was not intended to be a mode of exercise, it could serve as a step in progressive overload for those that are unable to perform ambulatory or higher intensity activities. Future studies should explore the impact of reducing daily SB and increasing LPA with a SED on changes in health and function in older adult populations.

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Table 1. Participant Characteristics (N=20)

	Mean (SD)
Age (yr)	71.9 (5.3)
Height (m)	1.68 (.1)
Weight (kg)	81.9 (15.5)
BMI (kg/m^2)	28.8 (3.9)
Met pedaling goal (% of participants)	
3+ days	100
4+ days	70
5+ days	60
6+ days	40
7 days	35
SB (minutes/day)	593.2 (66.1)
Median SB bout length (minutes)	18.3 (2.0)
LPA (minutes/day)	238.5 (47.2)
MVPA (minutes/day)	25.0 (26.5)
Total Wear Time (minutes/day)	856.7 (59.4)

yr = year, m = meters, kg = kilograms, SB = sedentary behavior, LPA = light-intensity physical activity, MVPA = moderate- to vigorous-intensity physical activity.

Table 2. In-home seated pedaling patterns (N=20)

	15 min (n=5)	30 min (n=5)	45 min (n=5)	60 min (n=5)	p (trend)
Met pedaling goal 3+ days (%)	100	100	100	100	1.000
Time pedaled (minutes/day)	21.1 (5.5)	33.8 (7.7)	64.2 (19.1)	64.7 (5.2)	<.001
Total weekly pedaling duration (minutes)	104.5 (41.0)	157.6 (94.0)	323.6 (45.8)	390.8 (122.4)	<.001
Days goal met	4.8 (1.6)	4.2 (1.8)	5.4 (1.7)	5.8 (1.8)	.500
Pedaling bouts per session	1.3 (.5)	1.5 (.6)	2.2 (.9)	2.6 (1.4)	.169
Average pedaling bout (minutes)	17.9 (2.1)	26.6 (4.8)	35.8 (8.9)	36.2 (10.2)	.270
Revolutions per minute	58.5 (19.2)	50.7 (15.6)	38.9 (17.5)	55.5 (26.7)	.457
Pedaled Days:					
SB (minutes/day)	548.3 (30.5)	622.5 (87.1)	638.6 (34.7)	571.1 (42.1)	.075
LPA (minutes/day)	249.6 (52.7)	211.6 (19.6)	220.2 (55.7)	274.1 (56.1)	.073
MVPA (minutes/day)	16.1(9.8)	21.6 (18.6)	31.0 (38.2)	43.1 (35.7)	.636
Wear time (minutes/day)	814.0 (55.2)	849.3 (66.7)	889.8 (39.7)	888.9 (63.0)	.152
Met MVPA recommendation (%)	0	20	20	60	.186

Values labeled as mean (standard deviation) unless otherwise noted. Total wear time on pedal days was included as a covariate for pedal day SB, LPA, and MVPA one-way ANOVA. Unadjusted values for SB, LPA, and MVPA are provided in the table. Met MVPA recommendation was determined based on Freedson (2008) cut-points (SB: < 100 CPM, LPA: 100-1951 CPM, MVPA: ≥1952 CPM) for accelerometer MVPA and the Physical Activity Advisory Committee Guidelines (USDHHS, 2008). SB = sedentary behavior, LPA = light-intensity physical activity, MVPA = moderate- to vigorous-intensity physical activity.

Table 3. Daily SB and PA adjusted for seated pedaling time (N=20)

	15 Min (n=5)	30 Min (n=5)	45 Min (n=5)	60 Min (n=5)
Unadjusted SB (minutes/day)	548.3 (30.5)	622.5 (87.1)	638.6 (34.7)	571.1 (42.1)
Pedaling duration (minutes/day)	21.1 (5.5)	33.8 (7.7)	64.2 (19.1)	64.7 (5.2)
Adjusted SB (minutes/day)	527.2 (28.5)	588.6 (93.1)	574.5 (51.5)	506.4 (40.3)
%Δ in SB	-3.95	-5.44	-10.05	-11.33
Cohen's d for SB	0.715	0.376	1.460	1.57
Unadjusted LPA (minutes/day)	249.6 (52.7)	211.6 (19.6)	220.2 (55.7)	274.1 (56.1)
Pedaling duration (minutes/day)	21.1 (5.5)	33.8 (7.7)	64.2 (19.1)	64.7 (5.2)
Adjusted LPA (minutes/day)	270.2 (48.3)	245.5 (23.3)	284.5 (73.1)	338.8 (51.7)
%Δ in LPA	+8.25	+15.99	+29.13	+23.6
Cohen's d for LPA	0.408	1.575	0.989	1.2
MVPA	15 (9.9)	15.3 (16.9)	27.7 (33.7)	43.7 (36.1)
Wear Time	745.2 (58.9)	849.3 (66.7)	843.2 (98.6)	888.9 (63.0)

Cohen’s d was calculated based on the mean differences between the original and adjusted values of pedal day SB and LPA. Adjusted SB values were calculated by manually subtracting individual daily pedaling minutes from pedaling day SB. Similarly, adjusted LPA values were calculated by manually adding individual daily pedaling minutes to pedaling day LPA. Values labeled as mean (standard deviation) unless otherwise noted. SB = sedentary behavior, LPA = light-intensity physical activity, MVPA = moderate- to vigorous-intensity physical activity.

Table 4. Participant experience questionnaire responses (N=20)

	Median Response Score				1	2	3	4	5
Question item	15 min	30 min	45 min	60 min	Response Proportions (%)				
1. How often did you feel that the duration of your recommended goal was sufficient?	4	4	4	4	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					5	15	10	35	35
2. While pedaling, how often did you feel that you were thinking of your recommended goal duration?	3	2	2	2	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					25	50	10	10	5
3. How often did you feel that the daily goal motivated you to complete the pedaling time?	4	4	2	4	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					10	15	5	45	25
4. How often did you feel that the addition of the seated elliptical interrupted your typical seated activities?	2	1	1	1	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					55	30	10	5	0
5. How comfortable was it to use the seated elliptical?	2	1	2	2	Very comfortable	Fairly comfortable	Somewhat comfortable	Uncomfortable	Very uncomfortable
					45	25	20	10	0
6. How easy was it to use the seated elliptical in multiple short periods?	2	2	2	1	Very easy	Fairly easy	Neither easy or difficult	Difficult	Very difficult
					50	30	15	5	0
7. How easy was it to use the seated elliptical in for extended periods?	2	2	2	1	Very easy	Fairly easy	Neither easy or difficult	Difficult	Very difficult
					45	30	20	5	0
8. Overall, how easy was it to use the seated elliptical?	2	2	2	1	Very easy	Fairly easy	Neither easy or difficult	Difficult	Very difficult
					55	30	10	5	0
9. How often did you feel satisfied after using the seated elliptical?	4	4	4	2	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					5	15	0	50	30
10. Was it easy or difficult to manage other tasks while pedaling the seated elliptical?	2	2	2	3	Very easy	Fairly easy	Neither easy or difficult	Difficult	Very difficult
					30	35	20	15	0

11. Was it easy to add the seated elliptical into your daily life?	2	2	2	2	Very easy	Fairly easy	Neither easy or difficult	Difficult	Very difficult
					30	55	15	0	0
12. How often did you feel that using the seated elliptical made it easy to be active?	4	4	3	4	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					15	10	10	50	15
13. How often did you feel prepared to use the seated elliptical during the trial period?	5	5	5	4	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					0	0	0	35	65
14. How often did you experience pain or discomfort while pedaling the seated elliptical?	2	1	2	1	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					65	225	5	0	5
15. How often did you experience pain or discomfort after pedaling the seated elliptical?	1	2	1	1	Never or almost never	Some of the time	About half of the time	Most of the time	Always or almost always
					80	5	0	15	0
16. If you ask people who are important to you how often you should use the seated elliptical, they would say: "You should":	4	3	3	4	Never or almost never use it	Rarely use it	Sometimes use it	Very often use it	Always or almost always use it
					0	5	30	50	15
17. In your opinion, how beneficial or harmful do you think physical activity is to your health?	1	1	1	1	Very beneficial	Somewhat beneficial	Neither beneficial or harmful	Somewhat harmful	Very harmful
					85	10	5	0	0
18. In your opinion, how beneficial or harmful do you think prolonged sitting is to your health?	4	4	4	4	Very beneficial	Somewhat beneficial	Neither beneficial or harmful	Somewhat harmful	Very harmful
					10	5	10	40	35

Table 5. Positive and negative responses with seated elliptical use

Was there anything you liked about the seated elliptical?	“Good for bad weather days.” “Very easy to use while watching television.” “It gave me a feeling of accomplishment while watching TV.” “Made it easy to move; i.e., easy to add movement to my daily routine.” “Easy to use.” “It is a convenient way to get exercise while accomplishing other tasks.” “Pedaling-seems to improve circulation and strengthen my legs.” “It pedals easily and smoothly.” “Ease of use when pedaling.” “Easy to do while watching TV.” “The exercise.” “Compactness.” “Easy to use & did not interfere with some activities.” “It was convenient to use.” “Reminds me (that) I need to be active and exercise.” “Compact, easy to use.” “Leg motion; keeping active.” “The location (my apartment); size and easy to use.” “Felt like I was doing some exercise.”

Was there anything you did not like about the seated elliptical?	“The digital screen was too small.” “Uncomfortable for my fee.t” “I wanted to be standing rather than sitting and moving more of my body (upper body).” “Would like to do more upper body exercise.” “No resistance. Did not feel any muscle benefits.” “Would like to have tried harder pedaling.”

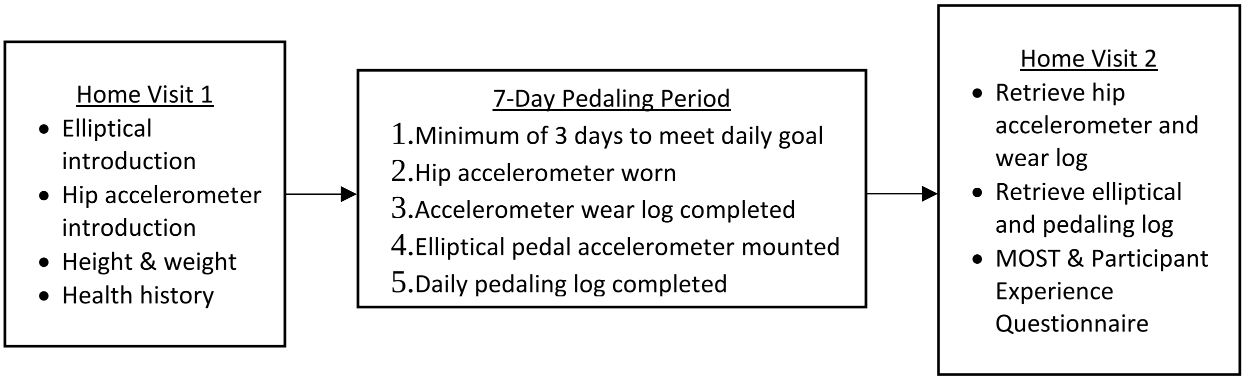

Figure 1. Summary of home visits and trial pedaling period.

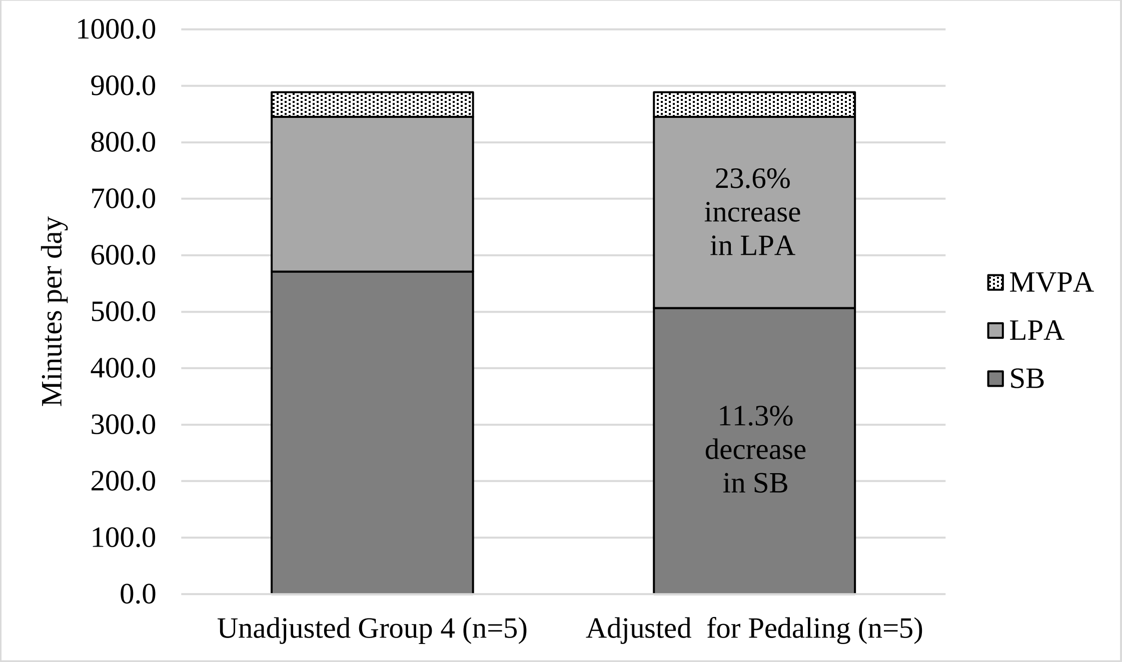

Figure 2. Accelerometer-derived daily SB and PA unadjusted and adjusted for pedaling in the 60 minute group (n=5).

CHAPTER V: REPLACING SEDENTARY BEHAVIOR WITH LIGHT INTENSITY PHYSICAL ACTIVITY IN THE HOMES OF OLDER ADULTS: PILOT RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

INTRODUCTION: Older adults spend approximately 65-80% of their day in sedentary behavior (SB) with most sedentary pursuits occurring in the home. Replacing SB time with light-intensity physical activity (LPA) is linked to better geriatric-relative health outcomes but few effective and practical interventions have been tested in older adults. The purpose of this study is to determine the effectiveness of replacing a SB with LPA using a seated elliptical pedaling device (SED) in the homes of older adults. METHODS: Twenty-one older adults were randomized into an 8-week home-based SB intervention using the SED elliptical group (EG) or a control group (CG). Participants completed baseline measurements, an intervention/control period, and follow-up measurements for objective SB and functional assessments. Group, time, and interaction effects were analyzed using an intention-to-treat and per protocol mixed model. RESULTS: Twenty-one older adults (13 female; 76.6 ± 6.7 years) completed baseline and 8-week follow-up assessments. There was a significant group by time interaction effect for daily SB ($p=0.003$) and LPA ($p=0.002$) indicating the effectiveness of the intervention to reduce daily SB and increase LPA. Specifically, individuals in the EG experienced a 7.3% reduction in daily SB which translated to a 7.1% increase in daily LPA. No significant intervention effect was identified for functional changes with most measures reporting a small effect size. CONCLUSION: A SED appears to be an effective and practical approach to reduce SB in the homes of older adults.

Larger trials using this device to determine effectiveness in altering geriatric-relevant health outcomes are warranted.

INTRODUCTION

Older adults accumulate approximately 65-80% of their waking hours in sedentary behavior (SB) which is greater than any other age group (de Rezende et al., 2014, Harvey et al. 2015). Distinct from physical inactivity, SB is characterized as a seated or lying posture with low energy expenditure (Sedentary Behavior Research Network, 2012) and has been negatively linked to several geriatric-related health outcomes, such as diabetes, physical functioning, cognitive functioning, independence, quality of life, and premature mortality (Buman et al., 2010, Bann et al., 2015, Gennuso et al., 2013, Kim et al 2013, Copeland et al. 2017, Loprinzi et al., 2015). The high prevalence of SB in older adults (Matthews et al 2012), progressive age-related displacement of PA to SB (Jefferis et al., 2015), and reduced odds for healthy aging with elevated SB presenting a paramount public health concern.

Sedentary behavior interventions are a feasible approach to reducing older adults' sitting time, but questions of practicality and acceptability have been raised (Copeland et al., 2017). Most SB interventions primarily aim to interrupt or reduce the time spent in specific tasks while seated or lying, including restricting access to TV time (Asoaka et al., 2007), TV commercial activity breaks (Steeves et al., 2017), and tactile feedback prompts (Harvey et al., 2018). Further, when SB is interrupted it is not generally reported how time-use is reallocated to other activities with two intervention studies reporting sitting time was primarily replaced by standing rather than stepping (Rosenberg et al 2015, Lewis et al 2016). This is important to distinguish with standing and stepping representing distinct physical stimuli with varied metabolic responses (Lerma et al, 2017). Using a seated elliptical pedaling device (SED) during seated tasks has shown promise as a strategy to optimize acceptability and effectiveness in SB reduction efforts by allowing the individual to maintain performance of the underlying seated task and directly target time-use substitution of SB with light-intensity physical activity (LPA) (Lerma et al., 2017).

With limited reporting on the effectiveness of SB interventions in older adults, even fewer have reported their impact on geriatric-relevant health outcomes and only two studies have reported functional outcomes in community dwelling older adults. Findings from these studies were promising with small improvements in the chair rise Sit-to-Stand (STS) (Barone Gibbs et al., 2017) and gait speed tests (Rosenberg et al., 2015), but further research is needed to confirm these preliminary findings. Therefore, the primary aim of this study is to assess the effectiveness of progressively increasing SED pedaling time to reduce SB in the homes of older adults over eight weeks. A secondary aim is to measure the impact of replacing SB with a seated LPA on functional outcomes in older adults. It is hypothesized that older adults in an intervention elliptical group (EG) using the SED will experience reduced SB compared to a control group (CG) and reductions in SB time will lead to improved measures of physical function.

METHODS

Participants

Twenty-one older adults were recruited to participate in this pilot randomized controlled trial. Research participants were recruited through the use of public flyers, laboratory website advertisements, and a research participant registry. Participants were screened over the phone and included in the study if they are 60+ years old, from the greater Milwaukee area, able to perform at least two minutes of consecutive light-intensity pedaling without difficulty or discomfort, and self-report at least four hours per day of sitting. Participants were excluded if they have had a cardiovascular event or psychological event in the past 12 months or any orthopedic condition that may limit their ability to perform a light-intensity pedaling action. Ethical approval was provided by the University's Institutional Review Board (*ID# 18.186*).

Study Overview

This 8-week pilot randomized controlled trial was designed to investigate the effectiveness of a SED to progressively reduce SB and examine the impact of reduced SB on functional outcomes in community dwelling older adults. Eligible participants were instructed to complete baseline questionnaires about demographics, health history, SB and PA, and physical functioning. Also, participants were asked to wear a hip-worn Actigaph GT3X+ activity monitor to observe baseline SB and PA over a 7-day monitoring period (Week 0) and complete a daily wear-time log. Activity monitors and questionnaires were sent by mail. Once the baseline monitoring period was completed a research team member performed a home visit to collect anthropometric measures and conduct field-based functional assessments.

At the completion of baseline data collection during the home-visit, participants were randomly assigned into either the EG or CG based on an assigned study ID number using a stratified randomization process with blocks of 6 (Altman et al., 1999) at a 1:1 ratio. Group allocation was concealed in envelopes by a research assistant and revealed at the completion of baseline data collection during the home visit. A study overview and timeline for the EG can be found in Figure 1. The CG followed the same timeline for baseline and post-intervention testing.

Intervention

Study participants allocated into the EG received a SED (Stamina, In-Motion e1000, Springfield, MO) to be used in the home during typical seated activities over eight weeks. The SED was placed in the home based on the self-reported location with the highest time spent in SB and comfort. After undergoing a familiarization session with the SED, participants were informed how to track time spent pedaling using a timer on the SED and a daily pedaling log sheet. Participants were instructed to use the SED at a self-selected light-intensity pace and to accumulate time toward their daily goal. Across the first four weeks, participants in the intervention progressively incorporated the device into their daily SB time to accumulate a total of at least 30 minutes per day during week one, 40 minutes per day during week two, 50 minutes per day during week three, and 60 minutes per day during week four. During weeks four through eight, participants were asked to maintain a daily goal of 60 minutes per day of seated pedaling.

Over the course of eight weeks, a research team member made semi-scripted telephone calls to the homes of the participants. Weekly phone calls were made during weeks one and two, followed by bi-weekly calls during week four through eight. The telephone calls served as motivational coaching sessions to address self-monitoring, outcome expectations, barriers and facilitators, and self-efficacy based on social cognitive theory constructs to reduce SB and increase PA (Bandura et al. 2004). Additionally, the research team member provided supportive accountability which included encouraging the participant to complete the prescribed pedaling goals.

Control group

The CG underwent the same baseline assessments and were instructed to maintain their current level of activity for the next eight weeks. Following post-intervention testing, participants in the CG received the option of participating in the full intervention.

Measures

Participant characteristics

Participant demographics were collected using a health history questionnaire and anthropomotrics were collected using standard procedures with a portable scale and tape measure for body mass (nearest 0.01 kg) and height (nearest 0.1 cm), respectively, in the homes (Ferguson, 2014).

Sedentary behavior and physical activity

Sedentary behavior and PA was determined by accelerometry using a hip-worn Actigraph GT3X+ (Actigraph LLC, Pensacola, FL) activity monitor. The Actigraph GT3X+ was set at a sampling rate of 100Hz using a tri-axial accelerometer to measure human movement. The participants were instructed to wear the accelerometer around their hip in-line with their right knee during waking hours across a 7-day monitoring period in pre-test and during the final week of the intervention period (Week 8). Participants were also instructed to complete a daily wear-time log to confirm wear time. Actilife software version 6.13.3 was used to analyze the Actigraph data at 60-second epochs and a wear-time algorithm (Choi et al 2011) that was supplemented by the self-report logs. Activity-intensity was determined using counts per minute (CPM) cut-points derived from 60-second epochs (SB: <100 CPM, LPA: 100-1941 CPM, and MVPA: ≥1951 CPM) (Freedson, 1998). While the hip-mounted Actigraph GT3X+ is not designed to measure posture, inactivity as determined by low CPM values were operationalized to SB. Valid accelerometer wear time was determined as ≥ 10 hours per day for ≥ 4 days during the 7-day monitoring period. (Sasaki et al 2017). Accelerometer monitoring using the Actigraph GT3X+ has been reported as a valid and reliable measure of physical activity and SB in older adults (Freedson et al., 2011; Kozey-Keadle et al., 2011).

Pedaling adherence

Participants were provided a journal to record daily use of the SED. The journal contained an 8-week calendar outlining the daily minimum goal and participants were instructed to record the total accumulated daily pedaling duration displayed on the SED at the end of each day.

Physical function

Lower limb mobility was assessed in the homes of the study participants using six field based functional assessment, including usual gait speed (UGS), timed 5-repetition sit-to-stand test (STS), the Short Physical Performance Battery (SPPB), 3-meter timed up and go (TUG), 50-foot walk test (50W), and 5-step test. Usual gait speed was determined by the time it takes to traverse 3 meters and reported in speed (m/s). Two cones were separated on the floor by a distance of 3 meters. The participant was instructed to place both feet behind the start cone and walk at a normal pace with the use of a walking aid if needed. Timing began when the research team member states “go” and timing will end when the participant passes the finish cone. The UGS test is a valid and reliable measure of lower body functional ability and mortality risk in older adults (Munoz-Mendoza et al., 2010).

The STS test is a measure that assesses lower limb strength and power development, transitional movement, balance, and fall risk. The same chair was used in each home visit with the participant instructed to begin in a seated position with their arms folded across the chest. The participant was instructed to make a single attempt prior to beginning the test. If the participant successfully completed a single attempt, they were instructed to complete five consecutive transitions from a seated position to a standing position as quickly as they can without stopping. Timing began when the research team member said “go” and ended when the participant was in the final seated position. The STS test has been identified as a reliable and valid measure of physical function in community dwelling older adults (Bohannon et al., 2010).

The SPPB is composed of three sub-tests (balance, gait, and chair rise each with a score of 0-4 to provide a total score of 0-12. The balance component includes a progressive assessment including standing with feet side-by-side, semi-tandem, and full-tandem for a maximum duration of 10 seconds. The chair rise and gait components were obtained from the UGS and STS and scored according the SPPB criteria with the balance test. The SPPB is a valid and reliable measure of functional ability in diverse populations (Freire et al., 2012).

The TUG is a timed test that requires the participant to stand from a seated position walk to a designated distance of 3 meters and return to the chair in a seated position. The participant was instructed to begin in a seated position and may use their hands to aid while transition from a sit to stand position. Once in a standing position, the participant was instructed to move as quickly and safely as possible to a cone placed 3 meters away and turn around to walk back to the chair to return to a seated position. The timing began when the research team member said “go” and timing ended when the participant returned to the seated position. The TUG test is a valid and reliable measure of lower body function in older adults (Podsiadlo & Richardson, 1991).

The 50W is a component of the Physical Performance Test (Reuben and Siu, 1990) that is designed to assess motor function, balance, mobility, coordination, and endurance. In order to perform this in the home, a modified version of the test using a 12.5-foot course was used. Two cones separated by 12.5 feet in distance were placed on the floor to indicate a start, turning, and finish points. The participant were instructed to place both feet at a line of tape placed by the start cone and instructed that they will make three 180º turns en route to completing 50 feet of walking distance. The participant was instructed to complete their walk in a fast and safe manner. Timing began when the research team member said “go” and timing ended when the participant passed the finish cone. The 50W has a high test-retest reliability (Murphy et al., 2003) and has a high correlation with mobility status (Wang, Olson, and Protas, 2005).

To perform the 5-step test the participant were instructed to stand facing a step 4 inches in height and step up forward and down backward representing a single repetition, five times. The participant was instructed to perform the 5-step test as quickly and safely as possible. Timing began when the research team member said “go” and timing was stopped when both feet were on the floor after the final backward step. The 5-step test has an excellent test-retest reliability (Murphy et al., 2003) and is a valid measure of mobility ability (Wang, Olson, and Protas, 2005).

Statistical analysis

All data were analyzed using SPSS 24.0 (IBM, Chicago, IL). All variables were tested for normality by examining frequency distributions and residuals were tested using a Shapiro-Wilk test. Functional outcomes, including the UGS, TUG, STS, 50W, and 5-step were log transformed prior to analysis due to non-normal distributions. Descriptive statistics were performed on the participant demographics and baseline outcomes (mean ± SD). Independent *t* tests and chi-square statistics were implemented to identify if baseline differences existed between the EG and CG. Statistical analysis was performed using intention-to-treat (ITT) mixed models to measure effectiveness of the intervention to reduce SB and improve physical function across the 8-week period. All participants that completed baseline data and follow-up date collection were included in the ITT analysis in their original random group allocation. Each model tested for repeated measures for participant outcomes using baseline and follow up data to analyze changes in outcomes between and within groups. Additionally, a per-protocol (PP) mixed model analysis was performed including only the participants that adhered to the intervention. In the PP mixed models, individuals from the EG that that deviated from protocol but completed both baseline and follow-up testing were allocated to the CG. Participants that were re-allocated to the CG met less than 50% adherence or did not participate beyond week four of the intervention. CONSORT guidelines recommend the reporting of both ITT and PP in randomized controlled trials to allow readers to interpret the effect of the intervention where the ITT presents real life effectiveness and PP presents true efficacy (Ranganathan, Pramsh, & Aggarwal, 2016). Parameter estimates, standard error (SE), effect sizes, and p-value are provided for PA, SB, and functional outcome variables. The effect sizes for SB, PA, and functional outcomes are presented as a Cohen's *d*. All *p*-values were based on two-tailed tests with a criterion of 0.05 and a Bonferroni adjustment was used for multiple comparisons.

Two participants provided less than the predetermined valid wear time criteria of 4 days with greater or equal to 10 hours per day of activity wear time during the follow up assessment period. Missing data was imputed using last observation carried forward from baseline accelerometer data. This was justified due to the similarities among baseline and follow-up measures of the individual and relatively stable SB and PA among both groups (prior to pedal time adjustment in EG).

Results

Participant characteristics

Twenty-one participants (14 female; mean age: 76.6 ± 6.7 years) completed baseline and follow-up data collection. Baseline measurements indicated some heterogeneity in the activity levels and functional ability of the study participants. Although participants were randomly allocated into groups, there were significant differences between groups at baseline measurement, including body weight, daily MVPA, and UGS (Table 1).

Study retention and pedaling adherence

Study retention and adherence resulted in unexpected changes in group sizes and analysis to be performed. There were four participants that dropped out of the CG after randomization and before baseline data collection which led to unequal group sample sizes. Three participants in the EG indicated low adherence with one citing recurring pain from a previous ailment that flared up while performing the seated pedaling and the other found it difficult to include into their lifestyle due to changes in caregiving responsibilities during the intervention period. The CONSORT diagram for participant and ITT/PP flow can be found in Figure 1.

The seven participants that remained in the EG intervention presented an ability to progressively meet the prescribed daily pedaling goals with all but one of the participants achieving a predetermined 80% adherence rate. As a group, adherence was consistent across the intervention with no significant relationship between days and proportion of participants meeting the daily goal. Group summarized data for daily median pedaling time and daily adherence rates is can be found in Figure 2a-b.

Sedentary behavior and physical activity monitoring

Objective activity monitoring measurements for baseline and follow-up can be found in Table 2 and Figure 3. The ITT and PP analysis identified no significant difference between baseline and follow-up unadjusted SB in either the EG or CG. However, when the follow-up SB measurement for the EG was adjusted for pedal time, there was significant group by time interaction effect for daily SB time in both the ITT and PP mixed models (p = .008 and p = .003, respectively). In particular, the PP model identified that the intervention contributed to the 7.3% reduction in SB experienced in the EG compared to no significant change in SB in the CG.

Similarly, there were no significant differences in unadjusted LPA values for either group between baseline and follow-up. However, subsequent adjustment for pedal time led to a significant group by time interaction effect in both the ITT and PP mixed models (p = 0.007 and p = 0.002, respectively). Thus, the PP model identified that the intervention contributed to the 7.1% increase in LPA in the EG compared to no change in LPA in the CG. There was no significant change in MVPA for either group across the intervention.

Physical function

Descriptive and statistical analyses for baseline and follow-up assessments for a battery of functional measures can be found in Table 3. Overall, this study included a wide range of functional abilities with the EG exhibiting significantly slower UGS (p = 0.014) at baseline and overall trends toward lower functioning in the other measures. Among the battery of functional measures, there was a significant improvement in STS (p = 0.006) and 50W (p = 0.015) across the 8-week period for both groups, but no significant differences to indicate an intervention effect.

DISCUSSION

Primary findings from this pilot study indicate that a SED is an effective approach to replace daily SB with LPA in the homes of community dwelling older adults. Baseline and follow-up SB did not differ for either groups, but when follow-up SB was adjusted for pedaling time there was a large effect size and significant interaction effect for daily SB and LPA. Among those that adhered to the program, there was 7.3% reduction in daily SB which translated to a 7.1% increase in daily LPA. In relative, terms this was approximately a 30% increase in total daily LPA from baseline levels. Secondary outcomes of this studied identified that, in general, participants reported improvements in their functional health and performance during the phone interviews, but effect sizes were small and the intervention effect was not statistically significant.

These findings coincide with the limited number of SB interventions studies supporting the feasibility of reducing SB in community dwelling older adults (Copeland et al., 2018). Among these studies, intervention effects were mixed with some studies reporting objectively measured reductions in sitting time by 27 (Rosenberg et al., 2015) to 51 min/day (Lewis et al., 2016). Meanwhile, other studies did not find significant changes in daily SB, but did identify changes in SB patterns with increased SB bout fragmentation (Gardiner et al., 2011, Fanning et al, 2016, Barone Gibbs et al., 2017, Lee and King, 2003). SB bout fragmentation was not reported in this study, but individuals in the EG did experience reduced total daily SB by up to 60 minutes while reporting multiple bouts per day.

Interventions to reduce SB are still in their infancy, but best practices are becoming more apparent. In a meta-analysis of SB interventions, the greatest reductions in reducing daily sitting time were found in interventions that specifically target SB, rather than focus on increasing daily PA or combined lifestyle interventions (Martin et al, 2016). Further, the context of SB is of importance when designing effective interventions that target relevant and unfavorable SBs. One study reported 70% of older adults’ SB occurred in the home with 84% of this home-based SB time spent watching TV (Leask et al., 2015). While not all sitting activities are linked to adverse health outcomes, passive activities like increased TV viewing have relatively greater associated risks to mobility limitations, frailty, and mortality in older adults (Garcia-Esquinas et al., 2017;

Dunstan et al., 2010). In the current study, the topographical nature of the SED allowed the older adult participants to convert passive activities like TV viewing to a physically active time with the ability to maintain the uninterrupted enjoyment of the underlying activity.

Factors that contribute to the adherence to SB and PA interventions are complex and not completely understood. Unpublished pilot data using this device in a laboratory-based setting identified modest differences in satisfaction and ease of use when applying pedaling at a self-determined pedaling rate compared to a higher intensity prescribed. Therefore, it appears that activity intensity may interrupt enjoyment of the underlying task. Further, the standards of adherence in exercise interventions may not be equivalently suited for SB interventions that utilize LPA. In particular, it may be assumed that a missed exercise bout is unlikely to be matched by an equivalent stimulus outside of the training session. However, opting out of pedaling the SED may be superseded by light-intensity ambulatory activities which was suggested by high activity counts on non-adhering days of some but not all participants. It was the aim of this study to allow participants to pedal at a self-determined light-intensity, as long as they did not interrupt their underlying daily activity and were able to complete their daily duration goal. Interestingly, several of the participants initially expressed doubt about their ability to accumulate 60 minutes of pedaling in a day. However, during phone interviews several of the participants were surprised by their ability to reach 60+ minutes of pedaling in a day and most participants stated that they had either purchased or were interested in purchasing the SED after completion of the study. Due to the expressed interest, studies should examine the use of this device beyond eight weeks to determine the long-term adherence to this device.

To date, there are only three SB intervention studies in older adults that have included physical function as a health outcome. Interestingly, these studies reported improvements in STS

(Barone Gibbs et al., 2016, Harvey et al., 2018), TUG (Harvey et al., 2018), and 400-meter walking time (Rosenberg et al., 2015), but minimal or no changes in daily SB time (Barone Gibbs et al., 2017, Harvey et al., 2018, Rosenberg et al., 2015). Efforts to influence functional health in older adults have primarily involved interventions to increase MVPA including aerobic, balance, and strength training. Higher intensity activities are an effective stimulus to facilitate functional improvements in community dwelling older adults (Pahor et al., 2006) and may be a *best buy* alternative for minute-for-minute effect size. However, recent epidemiological reports have identified that reallocating 30 to 60 minutes of daily SB time to a LPA or a combination of LPA and MVPA may be a more practical and feasible approach to achieve beneficial gains in physical health of older adults (Buman et al., 2010, Lerma et al., 2017). A systematic review identified that low-intensity exercise does provide modest improvements in function along with better adherence, reduced injury risk, and longer sustainability compared to higher intensity activities (Tse, Wong, & Lee, 2015). Regardless of the substitution activity intensity, breaking up or reducing time spent in SB is identified with an ability to halt or reverse the catabolic properties of SB (Bey et al., 2003). However, due to the slow, progressive nature of SB on functional health, immediate changes in functional health may be more apparent and detectable in those that are less functioning. Further, the functional assessments used in this pilot study are presented with ceiling effects. Therefore individuals that are of moderate-to-high functioning may not experience the same effect per treatment as individuals of lower-functional status. Phone interviews revealed that participants with lower baseline functional status did perceive improved lower limb stamina and the ability to perform longer pedaling bouts, but measureable changes were not significant between groups. Interestingly, both EG and CG measured significant improvements in particular functional tests. This may be due to changes in weather patterns during the spring and summer months which may have obscured any small effects from the SED intervention. However, there were no significant differences in daily SB or PA in CG or prior to adjusting for pedal time.

Strengths of this study include a novel topographical strategy to add a LPA to a typical seated activity. This approach may be more practical than interventions aimed at interrupting or replacing typical seated leisure activities. Other strengths include the use of objective SB, PA, and functional assessments. While self-report SB and PA can provide the added benefit of providing the context of the typical SB activities, they often underestimate daily SB and over-estimate PA (Shiroma et al., 2015). The Actigraph accelerometer device used to estimate SB time in this study did not include an inclinometer to measure posture. However, Chastin et al. (2016) identified that when using the Actigraph device total SB time was a measure that is considered accurate and sensitive to change. Also, the hip location of the Actigraph device allowed for an analysis to mutually measure SB time and adjust for pedaling time. The functional assessments used in this study are standardized and allow for an objective determination of function health, but are susceptible to ceiling effects. The effect sizes of reducing SB on these measures of physical function were minimal and statistical significance will require large sample sizes or the development of measures with increased sensitivity to functional changes. Regardless, the effects were positive and the participant feedback was encouraging (data not shown). A key limitation to this pilot study included a small sample size which contributed to the underpowered functional outcomes. However, as previously stated only three studies have reported functional outcomes from a SB intervention, therefore these outcomes were exploratory in nature and effect size estimates were provided to inform future studies. Another key strength was that this study included older adults which are an underrepresented sample in SB intervention studies. Interestingly, this older adult sample varied in functional capacities ranging from very low functioning to high functioning potentially adding variance in the responsiveness to the intervention.

CONCLUSION

In conclusion, the SED provided a practical approach to reducing SB in older adults up to durations that are considered clinically relevant according to epidemiological research with moderate to high adherence rates. Sedentary behavior is increasingly becoming a relevant public health concern with a growing and aging older adult population living in a society that is increasingly prone to sitting. The effect sizes of replacing SB with LPA on lower limb physical function were small, as anticipated, across an eight week intervention. If improvements in physical function are desired, the current level of function, capability of performing PA, and intensity of stimulus should be considered. Based on the trend toward improved physical function and the acceptability of the SED, longer-term interventions with larger sample sizes are warranted.

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Table 1. Participant characteristics at baseline (N=21)

	EG (n=11)	CG (n=10)	p for difference
Sex			
Male	5 (41.6%)	2 (20%)	.381
Female	6 (58.4%)	8 (80%)	
Age (yr)	75.5 ± 7.4	77.9 ± 5.9	.488
Height (m)	1.7 ± .1	1.6 ± .1	.109
Weight (kg)	90.2 ± 29.0	75.7 ± 11.0	.037
Body mass index (kg/m^2)	31.0 ± 6.2	28.6 ± 4.3	.403
SB (minutes/day)	636.5 ± 102.7	547.7 ± 105.2	.860
LPA (minutes/day)	182.6 ± 67.0	253.4 ± 101.4	.327
MVPA (minutes/day)	4.6 ± 5.5	16.1 ± 17.9	<.001
Total wear time (minutes/day)	823.6 ± 122.9	817.2 ± 100.5	.810
SPPB	7.8 ± 2.0	9.1 ± 1.8	.312
Balance	3.2 ± 1.2	3.6 ± 1.0	.367
Gait	3.0 ± 1.0	3.5 ± .7	.185
Chair rise	1.6 ± 1.0	1.9 ± 1.0	.360
UGS (m/sec)	.71 ± .1	.90 ± .1	.014
STS (sec)	16.5 ± 3.7	16.4 ± 3.3	.420
TUG (sec)	11.2 ± 3.9	9.0 ± 1.9	.072
50W (m/sec)	.9 ± .15	.88 ± .11	.736
5-step test (sec)	15.6 ± 4.6	13.5 ± 2.6	.215

Data is presented as mean ± SD or n (%).Statistical comparisons were performed on log transformed values for MVPA, UGS, STS, TUG, 50W, and 5-step test and are displayed in their original value. A Fisher's exact test was performed to test for significant relationships for gender and group allocation. The short physical performance battery (SPPB) carries a score of 0-12 with each subcomponent scored 0-4. Yr = year, m = meter, kg = kilogram, m/s = meters per second, sec = seconds

Table 2. Objective baseline and follow-up physical activity and sedentary behavior (n=21)

		Baseline	Week 8	p (time)	Week 8 Adjusted for Pedal Time	Difference Baseline vs Adjusted Week 8	Cohen's d	p (Group)	p (Time)	p (Interaction)
Intention to Treat										
Daily SB (%)	EG	77.5 ± 7.2	76.9 ± 7.1	.851	71.8 ± 6.6	-5.7	-.83	.132	.051	.008
	CG	67.4 ± 12.9	68.4 ± 12.8							
Daily LPA (%)	EG	21.9 ± 6.7	22.3 ± 6.5	.748	27.5 ± 6.2	+5.6	+.87	.166	.052	.007
	CG	30.7 ± 11.4	29.7 ± 11.4							
Daily MVPA (%)	EG	0.5 ± 0.7	0.8 ± 0.8	.585	0.8 ± 0.8	+0.3	+.42	.052	.516	.583
	CG	1.9 ± 2.0	1.9 ± 1.9							
Per Protocol										
Daily SB (%)	EG	78.7 ± 6.3	78.5 ± 6.4	.936	71.4 ± 5.3	-7.3	-1.25	.210	.006	.003
	CG	68.1 ± 12.3	69.4 ± 11.7							
Daily LPA (%)	EG	20.9 ± 6.1	20.9 ± 5.7	.833	28.0 ± 5.7	+7.1	+1.20	.264	.005	.002
	CG	29.3 ± 10.8	28.9 ± 10.5							
Daily MVPA (%)	EG	0.4 ± 0.3	0.6 ± 0.8	.452	0.7 ± 0.8	+0.3	+.50	.065	.450	.666
	CG	1.7 ± 1.7	1.6 ± 1.9							

Adjusted SB values were calculated by manually subtracting group average daily pedaling durations from pedaling day SB. Similarly, adjusted LPA values were calculated by manually adding group average daily pedaling durations to pedaling day LPA. Values are labeled as mean ± standard deviation. Cohen’s d was calculated based on the mean differences between the baseline and adjusted week 8 values for SB, LPA, and MVPA. Intention to treat: EG n = 11, CG n = 10; Per Protocol: EG n = 8, CG = 13. SB = sedentary behavior; LPA = light-intensity physical activity; MVPA = moderate- to vigorous-intensity physical activity; EG = elliptical group; CG = control group.

Table 3. Objective and self-report physical function at baseline and follow up (n = 21)

		Baseline	Follow Up	%Δ	Cohen's d	p (Group)	p (Time)	p (Interaction)
SPPB (0-12)	EG	7.8 ± 2.0	8.6 ± 2.7	+10.3	+.34	.312	.374	.374
	CG	9.1 ± 1.8	9.1 ± 2.2	0	0			
UGS (m/sec)	EG	.71 ± .13	.76 ± .17	+7.0	+.33	.014	.453	.261
	CG	.90 ± .12	.90 ± .16	0	0			
STS (sec)	EG	16.5 ± 3.7	13.1 ± 4.5	-20.6	-.83	.420	.006	.275
	CG	16.9 ± 3.7	15.3 ± 5.3	-9.5	-.35			
TUG (sec)	EG	11.2 ± 3.9	14.5 ± 6.1	+29.5	+.64	.072	.094	.632
	CG	9.5 ± 2.2	11.0 ± 4.3	+15.8	+.44			
50W (m/sec)	EG	.90 ± .15	1.1 ± .40	+22.2	+.66	.736	.015	.645
	CG	.87 ± .15	1.0 ± .33	+14.9	+.51			
5-step test (sec)	EG	15.6 ± 4.6	15.9 ± 6.4	+1.9	+.05	.215	.071	.148
	CG	13.9 ± 4.0	12.6 ± 3.5	-9.4	-.35			

Mixed model statistical analysis for UGS, STS, TUG, 50W, and 5-step test were performed following log transformation. Non-transformed values are provided in the table. Only per protocol analysis is provided: EG n = 8, CG = 13. SPPB = short physical performance battery; UGS = 3-meter usual gait speed; STS = five time sit-to-stand; TUG = timed up and go; 50W = 50 foot-walk test; kg = kilogram; EG = elliptical group; CG = control group. For the STS, EG = 7 due to inability to perform the test at follow up.

Enrollment	Baseline Data Collection (Week 0)	Intervention period (Week 1-8)	Post-intervention follow-up (Week 9)	Analysis
• Prescreening and informed consent • Random group allocation • Scheduling	• 7-day pre-intervention AG monitoring period • In-home functional assessment • Orientation to progressive SED prescription	• EG follows progressive SED prescription • Motivational support calls (week 1,2,4,6,8) • 7-dayAG monitoring period (Week 8) • CG maintains current level of activity	• In-home functional assessment • Retrieve activity monitor, log, and SED	• Intention-to-treat mixed model analysis • Per-protocol analysis

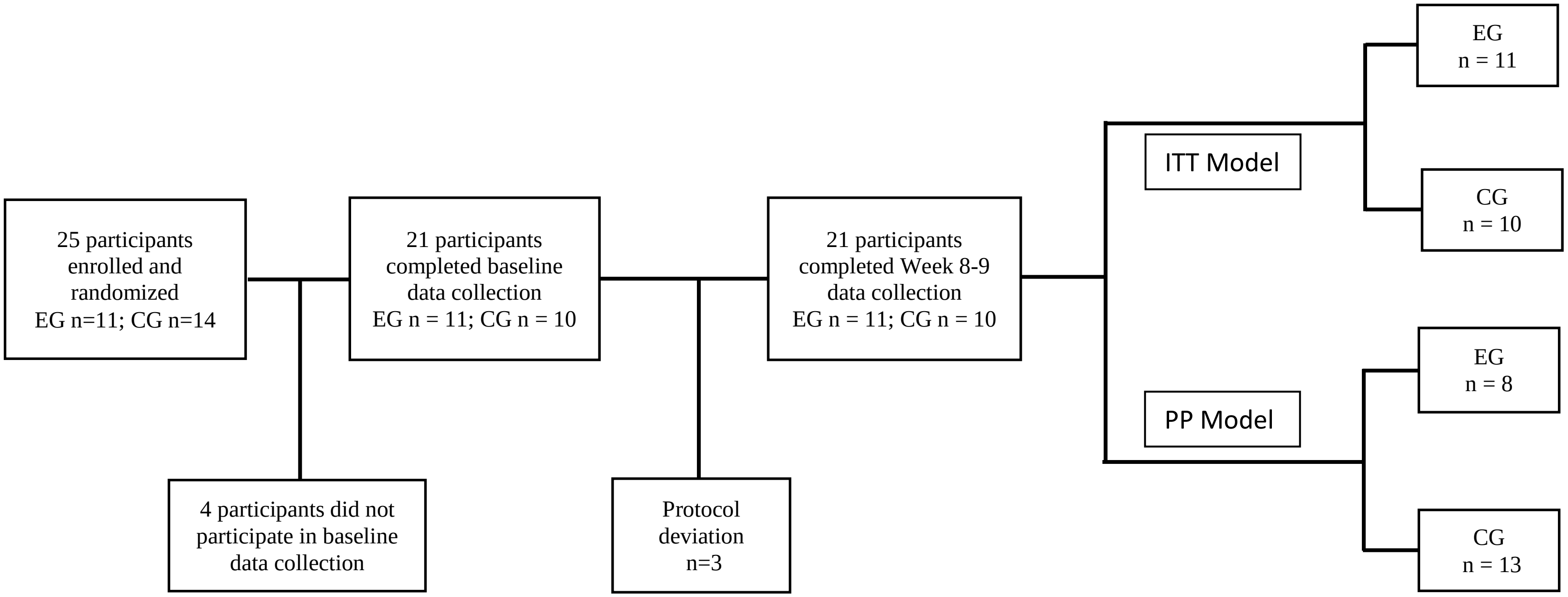
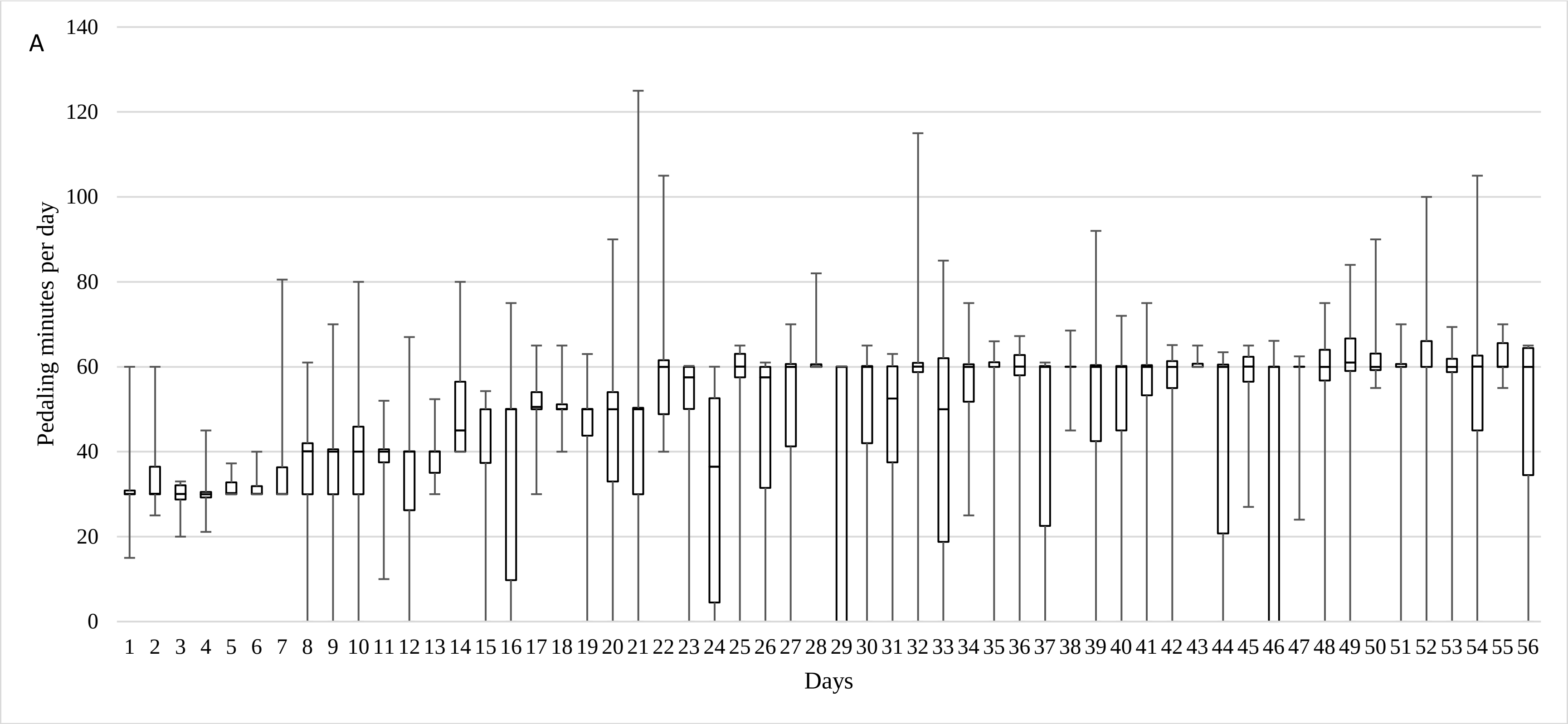


Figure 1. CONSORT diagram for study timeline, participant flow, and intention-to-treat/per-protocol analysis. SED = seated elliptical pedaling device; AG = Actigraph GT3X+ accelerometer; EG = elliptical group; CG = control group; ITT = intention-to-treat; PP = per-protocol.


A
Pedaling minutes per day
0
20
40
60
80
100
120
140
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Days

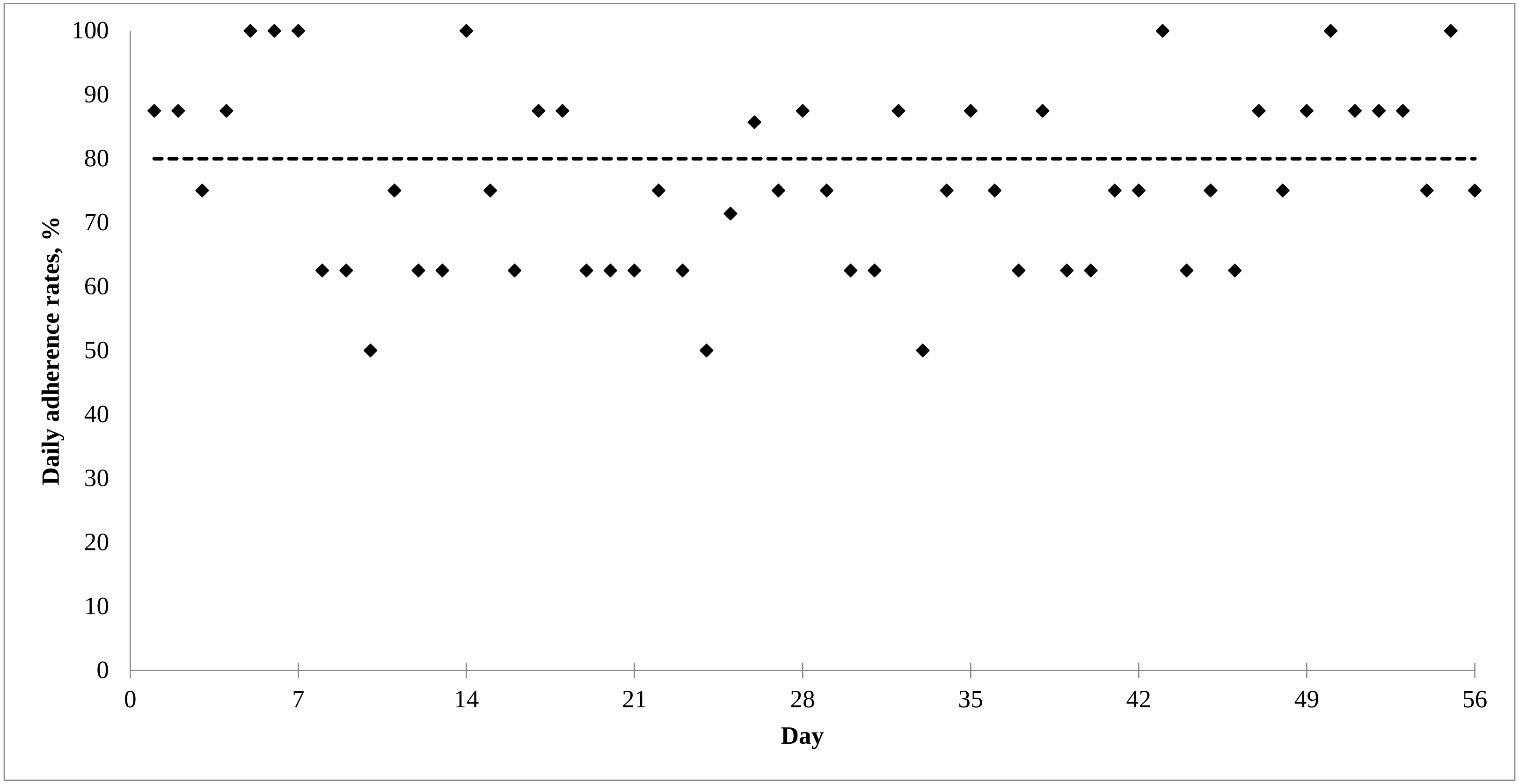


Figure 2a-b. Daily accumulated pedaling time and daily adherence. a) Box-and-whisker chart for minutes pedaled per day. Box indicates first and third quartiles, horizontal line inside box indicates median, and error bars indicate daily maximum and minimum values. b) Markers indicate elliptical group daily adherence rates and the dashed line represents the trend line. Data is represented by participants that did not deviate from the protocol (n = 21; EG = 8, CG = 13).

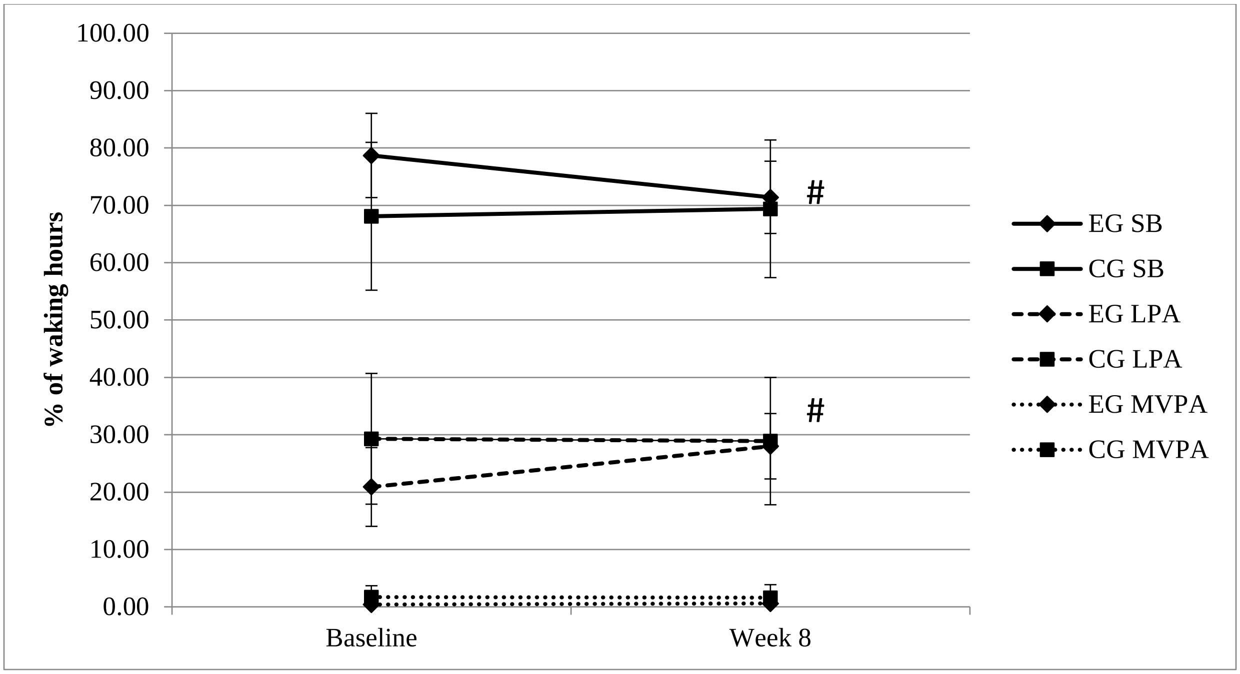


Figure 3. Baseline and Week 8 follow-up sedentary behavior and physical activity as a percent of waking hours (Per protocol: n = 21; EG = 8; CG = 13). The EG values are represented as adjusted SB and LPA based on pedaling time. EG = elliptical group; CG = control group; SB = sedentary behavior; LPA = light-intensity physical activity; MVPA = moderate- to vigorous-intensity physical activity, # = significant interaction effect ($p < 0.005$)

CHAPTER VI. CONCLUSION

Over the next three decades, we will see an older adult population that will notably increase in size with greater proportions achieving advanced old age. In older adulthood, gradual and progressive age-related reductions in physical function become manifest and lead to the inability to perform ADLs, a reduced quality of life, and risk of institutionalization. Meanwhile, population surveillance studies using objective measurements of human movement identify that between 2-17% of the older adult population meet the recommended MVPA guidelines with trends toward further reductions in PA and increased SB with each successive year (Sun et al., 2013). Further population surveillance has identified that older adults with greater durations of daily SB are at increased risk of reporting and experiencing functional limitations (Buman et al., 2010, Gennuso et al., 2013, Lerma et al., 2017). Thereby, the unwanted byproduct is a vicious cycle where increased SB accelerates reduced functional capacity and further precipitates reduced SB. Moreover, targeting increased PA and physical function does not necessarily translate to reduced daily SB (Martin et al., 2015) and interventions should target purposeful substitution of a SB with PA.

While MVPA is a potent stimulus for producing improvements in functional performance, there is evidence to suggest SB is negatively linked to function independent of time spent in MVPA. In chapter three, an observational study using an isotemporal substitution regression model identified that when replacing 60 minutes of SB with LPA, there was a statistically significant and clinically relevant improvement in walking speed. Further, replacing SB time with shared amounts of LPA and MVPA resulted in greater functional improvements across a battery of tests with increasing shares of MVPA resulting in more impactful improvements.

Notably, this study identifies that replacing SB with either LPA or MVPA is beneficial and a more feasible approach to increasing total daily PA may be to replace daily SB with LPA.

In chapter four, a pilot feasibility study was performed to assess the ability of a SED to be used in the homes of older adults for a one week period. Introducing a SED to seated activities of the home is a novel strategy to purposefully and subtly replace SB with LPA without interrupting the underlying seated activity. Because of the novel motion, it was unclear if older adults could accumulate up to 30 to 60 minutes of pedaling per day. This study found that there were no differences in the ability of older adults to accumulate 15, 30, 45, or 60 minutes of pedaling on three of the seven days with the device in their possession. Overall, the participants in the study found the SED to be convenient and easy to use without interrupting their typical seated activity. Longer trial periods should be conducted to measure the adherence and effectiveness of using a SED as a SB intervention to improve geriatric-related health outcomes.

In chapter five, a pilot randomized controlled trial was conducted to determine the effectiveness of a SED on replacing SB with LPA in the homes of older adults. The primary findings from this study indicated a significant interaction effect for the intervention over time with the EG experiencing a 7.6% reduction in daily SB which was transferred to LPA. The small sample size of the study did not have adequate statistical power to detect statistically significant changes in functional outcomes, but small to moderate effect sizes were reported for the design of future interventions. Similar to chapter four, participants in the EG reported the SED as easy and convenient to use while transitioning typically passive seated behaviors to become more active. However, EG dropouts indicated that ease of use, convenience, and ultimately adherence was dependent on the ability to place the device comfortably in the home. Individuals that could not find a comfortable and convenient placement for the SED in their home dropped out of the study. Further discussions on adherence among SB interventions are warranted. Specifically, when prescribed MVPA is not met it can be assumed that the replacement activity likely does not meet or exceed the prescribed activity. In comparison, non-adherence to a LPA replacement for SB may only be indicated by higher than typical SB as any equivalent or higher-intensity alternative to the LPA intervention may be just as beneficial as indicated in chapter three.

Findings from these studies provide paths to several different future inquiries. In particular, the impact of replacing SB with LPA on individuals of various baseline functional capacities should be explored. Anecdotal evidence form these study and theoretical evidence from the research literature suggest that there may be distinct functional benefits based on baseline levels of functioning. Future interventions should explore if distinct measurable benefits exits. Also, future interventions should explore the long-term adoption and adherence of the SED beyond an eight week period. The relatively low stimulus for mitigating a gradual, progressive decline in function may take longer to detect and should focus on maintenance rather than improvement in able-bodied community dwelling older adults. Context specific interventions may also be of importance, as retired individuals that tended to watch more television found this device most useful compared to those that were either working or performed computer tasks. Lastly, community and organizational buy-in is important. Sitting behaviors are largely influenced by social norms and the environment. Placing these devices in social settings, such as shared community spaces or TV rooms may serve as a catalyst for individual and community motivation to become more physically active. A key limitation to recruitment was the idea that the device and time commitment would be too burdensome. Often it took a brief trial period for participants to realize that using the SED during activities like television viewing was an enjoyable and practical way to increase daily PA.

Chapter Summary

Aging is linked to reduced daily PA and greater daily SB and those with increased time spent in SB are linked to greater risks in functional limitations and reduced performance. Population based studies suggest replacing SB with LPA as a practical and effective way to reduce or reverse age-related functional changes. A SED provided an acceptable and effective means to conveniently transform high-risk passive seated activities to LPA without interrupting the enjoyment of the underlying activities. Long-term studies with larger sample sizes including a diverse cohort of functional abilities are needed to confirm the short- and medium-term effectiveness of the SED to reduce daily SB on impacting geriatric-related health outcomes.

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APPENDICES

Appendix A
“Replacing SB with LPA: Pilot RCT” Pedaling log

ID #:____________

Date issued: _________

Seated Elliptical Daily Log

UW-Milwaukee - Physical Activity and Health Research Laboratory
Enderis Hall, Rm. 434 • (414)229-4392

Day	Date	Time Started (am/pm)	Time Stopped (am/pm)	Daily duration (add all bouts):	Daily Goal (min)
0	**Do Not Pedal**				
1					
2					

3					
4					
5					

6					
7					

Appendix B
“Replacing SB with LPA: Pilot RCT” Phone script

Physical Activity & Health Research Lab

Department of Kinesiology
Enderis Hall, Rm. 434   (414) 229-4392

Semi-Scripted Bi-Weekly Telephone Call:

Replacing sedentary behaviors with a seated light-intensity activity in older adults at risk for mobility disability

Phone Number: _________________
Bi-Weekly Call# (circle):

1 (week 1)
2 (week 2)
3 (week 4)
4 (week 6)
5 (week 8)

Introduction

Hello, my name is _____________ and I am a________________ working with the Physical Activity & Health Research Laboratory at the University of Wisconsin- Milwaukee. I’m calling for ____________________.

- **If the participant is not on the line or home, continue with to the person or voicemail:**
  Could you have _________________ please return my call and ask for ______________ at 414-229-4392. Thank you.

- **If the participant is on the line proceed with the script:**
  How are you doing today?
  I just want to check in to see how the elliptical pedaling is going and provide some information about the risks of sedentary behavior and benefits of replacing sedentary behavior with physical activity.

Comments:

Motivational Content

- Sedentary behaviors include any sitting or lying activity that results in a reduced energy expenditure. The purpose of your home elliptical device is to allow you to perform your typical seated activities, but to incorporate movement to the activity.

- Based on your baseline information, it is estimated that you spend approximately ____ % of your day in sedentary behavior with each sitting bout lasting an average of _____ min.

- Increased time spent sitting can compound age-related changes in physical function and mobility (Tikkanen et al, 2012).

Comments:

- Reducing your daily sedentary behavior by 60 minutes and replacing it with light activities is linked to clinically relevant changes in health and physical function (Lerma et al, 2017; Buman et al, 2010). Further benefits are experienced with greater durations and higher intensities of replacement activities. This can include improved ability to perform activities of daily living like standing up from a chair, taking the stairs, or walking a quarter mile.

- We have set a goal of reducing your daily sedentary behavior by pedaling ____ minutes per day this week.

Have you been able to meet this goal? ☐ Yes ☐ No

i. **If yes: Awesome keep it up!**
ii. **If no: What are some strategies that we can come up with to increase your daily pedaling?**

____
____
____

Elliptical use (Non-scripted encouragement as needed to promote safe and comfortable use of the elliptical)

Lastly, I have a few questions to ask regarding your use of the elliptical device in the home:

1. How comfortable is the device in its location?

   ☐ Very comfortable
   ☐ Fairly comfortable
   ☐ Someone comfortable
   ☐ Uncomfortable
   ☐ Very uncomfortable

   If not comfortable, why and what can be done to make it more comfortable:

   ____
   ____
   ____

2. How easy is the device to use in its location?

   ☐ Very easy
   ☐ Fairly easy
   ☐ Neither easy or difficult
   ☐ Difficult
   ☐ Very difficult

If not easy, why and what can be done to make it easier to use:

____

____

____

3. How often do you look forward to using the device?

☐ Never or almost never
☐ Some of the time
☐ About half of the time
☐ Most of the time
☐ Always or almost always

If not, what can be done to improve your experience while using the device:

____

____

____

4. How often did you feel that the addition of the seated elliptical interrupted your typical seated activities?

☐ Never or almost never
☐ Some of the time
☐ About half of the time
☐ Most of the time
☐ Always or almost always

If interrupting, how so and what can be done to reduce any interruptions:

____

____

____

Do you have any other comments regarding pedaling? ☐ Yes ☐ No

Non-elliptical sedentary behavior replacement:

- Outside of the location and activity where you are pedaling the portable elliptical, have you noticed other types of activities where you accumulate time spent seated? - **If yes,** list: ____ ____ ____	Comments:

- What are some strategies that we can include to interrupt this time which would be acceptable to you?

Have you been able to find other opportunities to break up or reduce time spent sitting throughout the day?

  a. **If yes,** what strategies have worked best for you?
  b.

  If no, provide examples from the list below if **<u>none</u>** mentioned by the participant:

    i. Standing while watching TV, reading, or talking on the phone
    ii. Walking for water breaks or standing during TV commercials
    iii. Parking further from store entrances
    iv. Finding safe areas to walk

- Have you noticed any changes in your ability to perform physical activities?

  ☐ Yes ☐ No

  If so, explain:

Concluding remarks:

Thank you for dedicating your time to answer some of these brief questions today. We will check back with you again in two weeks to discuss some of this information (unless this is their final week).

Have a great week!
Good bye.

Nicholas Louis Lerma

EDUCATION

Ph.D. Candidate, University of Wisconsin-Milwaukee (2018)
Department of Kinesiology
Area of Emphasis: Exercise Physiology
Dissertation title: *Replacing sedentary behavior with light intensity physical activity in older adults*
Advisor: Scott Strath, Ph.D.

Master of Arts, Central Michigan University (2013)
School of Health Sciences
Area of Emphasis: Exercise Science
Advisor: Roop Jayaraman, Ph.D.

Bachelor of Arts, Albion College (2007)
Department of Physical Education
Area of Emphasis: Exercise Science
Advisor: Roop Jayaraman, Ph.D.

Continuing education:
Graduate Certificate in Applied Gerontology (2015)
University of Wisconsin-Milwaukee
Center for Aging and Translational Research
School of Social Welfare

RESEARCH EXPERIENCE

Graduate research assistant:
University of Wisconsin-Milwaukee, Milwaukee, WI (2013-Present).
Physical Activity and Health Research Laboratory, College of Health Sciences, Department of Kinesiology. Lab directors: Dr. Scott Strath and Dr. Ann Swartz.

Central Michigan University, Mount Pleasant, MI (2010-2013).
Biology of Exercise Research Group/Wellness Central Weight Loss Program, School of Health Sciences. Lab directors: Dr. Roop Jayaraman and Dr. Richard Parr.
Muscle Cramp Laboratory, School of Health Sciences. Lab director: Dr. Jeff Edwards.

Undergraduate research assistant:
Michigan State University, East Lansing, MI (2006).
McCabe Molecular Physiology Laboratory, Department of Physiology. Lab director: Dr. Laura McCabe.

Albion College, Albion, MI (2005-2006).
Human Performance Laboratory, Department of Physical Education. Lab director: Dr. Roop Jayaraman.

RESEARCH INTERESTS

- Physical activity and sedentary behavior monitoring assessment.
- Physical activity interventions to maintain and/or improve functional performance across the lifespan.

TEACHING EXPERIENCE

Instructor:

University of Wisconsin-Milwaukee, Milwaukee, WI (2013-2018).

Online *(Teaching reviews available upon request).*

- KIN 230: Health Aspects of Exercise and Nutrition (Spring 2016, Fall 2016, Spring 2017, Summer 2017, Fall 2017, Summer 2018).

Face-to-Face *(Teaching reviews available upon request).*

- KIN 230: Health Aspects of Exercise and Nutrition (Spring 2015).
- KIN 290: Health & Wellness as We Age (Fall 2017).

Invited instructor:

- KIN 200: Introduction to Kinesiology (Fall 2013. Spring 2014, Spring 2016, Fall 2016).
- KIN 330: Exercise Physiology (Fall 2014).
- KIN 351: Sociological Aspects of Health & Human Movement (Fall 2014, Spring 2015, Fall 2015, Fall 2016).
- KIN 910/590: Current Topics in Human Kinetics (Spring 2017).
- SOC WRK 300: Aged to Perfection (Fall 2015, Fall 2016, Fall 2017).
- Milwaukee County Organization for Active Seniors in Society (OASIS) - Sedentary Behavior and Health (Spring 2015).
- St. John's on the Lake Senior Retirement Community - Sedentary Behavior and Health (Spring 2015).

Graduate teaching assistant:

University of Wisconsin-Milwaukee, Department of Kinesiology, Milwaukee, WI (2013-2015)

- KIN 330: Exercise Physiology Laboratory. Course instructor: Dr. Julie Rapps-Hedgecock (Fall 2013), Dr. Whitney Welch (Summer 2014), Dr. Ann Swartz (Fall 2014).
- KIN 400: Ethics and Values in the Health and Fitness Professions (Online). Course instructor: Dr. Laura Rooney (Spring 2015).
- KIN 430: Exercise Testing and Prescription Lab. Course instructor: Dr. Julie Rapps-Hedgecock (Spring 2014) and Dr. Jeremy Steeves (Spring 2015).

Central Michigan University, School of Health Sciences, Mount Pleasant, MI (2010-2013).

- HSC 201: Medical Terminology. Course instructor: Dr. Jeff Betts (2010-2013).
- HSC 214: Human Anatomy Laboratory. Course instructor: Dr. Bill Saltarelli (Fall 2011-Summer 2013).
- HSC 215: Human Physiology Laboratory. Course instructor: Dr. Jeff Betts and Mrs. Leslie Wallace (Fall 2010-Spring 2013).
- HSC 411: Pathophysiology (supplemental instruction). Course instructor: Professor Leslie Wallace (Spring 2012, Spring 2013).

- HSC 630: Regional Human Anatomy Laboratory. Course instructor: Dr. Bill Saltarelli and Dr. Peter Loubert (Summer 2012, Summer 2013).
- HSC 631: Graduate Exercise Physiology Laboratory. Course instructor: Dr. Jeff Edwards (Spring 2013).

K-12 teaching:

Full-time Substitute Teacher, Albion Public Schools, Albion, MI (2007-2010, Summer 2013, Summer 2015).

- Courses taught include physics, chemistry, biology, physical science, and life science courses.
- Principal: Mr. Derrick Crum.

AWARDS AND HONORS

Advanced Opportunity Program Fellowship Recipient, University of Wisconsin-Milwaukee (2015-2016, 2017-2018).

Physiological Measurement Highlights of 2016 Collection, IOP Science (2016).

NIH TL1 Trainee Fellowship Recipient, Clinical and Translational Science Institute of Southeast Wisconsin, Medical College of Wisconsin (2016-2017).

Helen Bader Applied Gerontology Award Recipient, University of Wisconsin-Milwaukee (2015-2016).

Helen Bader Applied Gerontology Award Recipient, University of Wisconsin-Milwaukee (2014-2015).

McNair Scholar Summer Research Opportunity Program, Michigan State University (2006).

Rose Gonzales Scholarship, Albion High School (2002).

CERTIFICATIONS HELD

- American Red Cross First Aid/CPR/AED certified (2013-Present).

PROFESSIONAL AFFILIATIONS

- Kinesiology Graduate Association, Vice President (2017-Present).
- Hispanics Professionals of Greater Milwaukee, Member (2016-Present).
- American College of Sports Medicine, Member (2006-Present).
- Midwest American College of Sports Medicine, Member (2006-Present).
- Phi Epsilon Kappa Albion College Chapter, Member (2005-2007).

PUBLICATIONS

Articles and papers published or accepted for publication:

Lerma, NL, Swartz, AM, Keenan, KG, Miller, NE, Cho, CC, & Strath, SJ. (2018). Isotemporal Substitution of Sedentary Behavior and Physical Activity on Function. Medicine and science in sports and exercise, 50(4), 792-800.

Panza, G, Stadler, J, Murray, D, **Lerma, NL**, Barrett, T, Pettit-Mee, R, & Edwards, J. (2017). The effects of acute passive stretching on cramp threshold frequency. *Journal of Athletic*, 52(10):918–923. doi: 10.4085/1062-6050-52.7.03.

Lerma, NL, Swartz, AM, Rowley, TW, Maeda, H, & Strath, SJ. (2017). Increasing the Energy Expenditure of Seated Activities in Older Adults with a Portable Elliptical Device. *Journal of Aging and Physical Activity*, 1:99-104. doi: 10.1123/japa.2015-0277.

Lerma, NL, Keenan, KG, Strath, SJ, Forseth, BM, Cho, CC, & Swartz, AM. (2016). Muscle activation and energy expenditure of sedentary behavior alternatives in younger and older adults. *Physiological Measurement*, 37: 1686-1700. doi: 10.1088/0967-3334/37/10/1686.

CONFERENCE PRESENTATIONS

Lerma, NL, Cho, CC, Maeda, H, Swartz, AM, & Strath SJ. Replacing Sedentary Time with Light Physical Activity Reduces Functoinal Limitations in Older Adults: NHANES 2003-2006. **American College of Sports Medicine, National Conference. Minneapolis, MN.** May 2018 (Poster).

Lerma, NL, Cho, CC, Maeda, H, Swartz, AM, & Strath SJ. Replacing Sedentary Time with Light Physical Activity Reduces Functoinal Limitations in Older Adults: NHANES 2003-2006. **Health Research Symposium, UW-Milwaukee, Milwaukee, WI** May 2018 (Poster).

Lerma, NL, Keenan, K, Cho, CC, Miller, NE & Swartz, AM, & Strath, SJ. *Isotemporal Substitution of Sedentary Behavior and Physical Activity on Physical Performance in Older Adults*. **American College of Sports Medicine, National Conference. Denver, CO** May 2017 (Thematic Poster).

Lerma, NL, Keenan, K, Cho, CC, Miller, NE & Swartz, AM, & Strath, SJ. *Isotemporal Substitution of Sedentary Behavior and Physical Activity on Physical Performance in Older Adults*. **College of Health Sciences Research Symposium, UW-Milwaukee. Milwaukee, WI** May 2017 (Poster).

Lerma, NL, Strath, SJ, Keenan, K, Forseth, B, Cho, CC, & Swartz, AM. *Age Alters Muscle Activation but not Energy Expenditure During Sedentary Behavior Alternatives*. **American College of Sports Medicine, National Conference. Boston, MA** May 2016 (Poster).

Lerma, NL, Strath, SJ, Keenan, K, Forseth, B, Cho, CC, & Swartz, AM. *Age Alters Muscle Activation but not Energy Expenditure During Sedentary Behavior Alternatives*. **College of Health Sciences Research Symposium, UW-Milwaukee. Milwaukee, WI** May 2016 (Lecture).

Lerma, NL, Strath, SJ, Keenan, K, Forseth, B, Cho, CC, & Swartz, AM. *The Effects of Altering Sitting Behavior on Energy Expenditure and Muscle Activation*. **International Conference of Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM), Limerick, Ireland** June 2015 (Poster).

Lerma NL, Swartz AM, Rowley TW, Maeda H, and Strath SJ. *Increasing Energy Cost of Sedentary Behaviors in Older Adults Using a Portable Elliptical Device: Pilot Examination.* **American College of Sports Medicine, National Conference. San Diego, CA** May 2015 (Poster).

Lerma NL, Swartz AM, Rowley TW, Maeda H, and Strath SJ. *Increasing Energy Cost of Sedentary Behaviors in Older Adults Using a Portable Elliptical Device: Pilot Examination.* **College of Health Sciences Research Symposium, UW-Milwaukee. Milwaukee, WI** May 2015 (Poster).

Lerma, NL, Swartz, AM, Miller, NE, Keenan, K, & Strath, SJ. *Objectively determined physical activity and measures of physical function in older adults***. American College of Sports Medicine Conference, National Conference. Orlando, FL** May 2014 (Poster).

Panza GS, Stadler J, Murray D, **Lerma NL,** Barret T, Pettit-Mee R, & Edwards J. *The Effects of Acute Passive Static Stretching on Cramp Threshold Frequency*. **American College of Sports Medicine, National Conference. Orlando, FL.** May 2014 (Poster).

Maeda, H & **Lerma, NL**. *Sedentary behavior: promoting physical activity is not enough.* **Wisconsin Public Health Association Conference, Milwaukee, WI** May 2014 (Poster).

Lerma, NL, Maeda, H, Garcia Atonson, B, Trepasso, T, & Strath, SJ. *Multiple health-based point of decision prompts and an elevator survey to alter elevator and stair use.* **College of Health Sciences Research Symposium, UW-Milwaukee.** May 2014 (Poster).

Smith, VG, Elder, KC, **Lerma, NL**, Parr, RB, Jayaraman, RC. *Changes in abdominal adiposity in overweight and obese subjects following an 8-week community weight management program.* **American College of Sports Medicine, National Conference. Denver, CO.** June 2011 (Poster).

Lerma, NL, Parr, R, Smith, VG, Elder, K, & Jayaraman, RC. *Effectiveness of an 8-week community based weight management program on blood lipids, 2000-2009.* **American College of Sports Medicine, National Conference Denver, CO.** June 2011 (Poster).

Lerma, NL, Parr, R, Smith, VG, Elder, K, & Jayaraman, RC. *Effect of a community weight loss program on blood lipids.* **Student Research and Creative Endeavors Exhibition, Central Michigan University.** March 2011 (Poster).

Smith, VG, Parr, R, **Lerma, NL**, Elder, K, & Jayaraman, RC. *Effect of a community weight loss program on body composition.* **American College of Sports Medicine, National Conference, Denver, CO.** June 2011 (Poster).

Lerma, NL, Parr, R, Smith, VG, Elder, K, & Jayaraman, RC. *Effect of a community weight loss program on blood lipids*. **Midwest Graduate Research Symposium, University of Toledo.** March 2011 (Poster).

Smith, VG, Parr, R, **Lerma, NL**, Elder, K, & Jayaraman, RC. *Effect of a community weight loss program on body composition.* **American College of Sports Medicine Conference, Midwest Conference. IUPUI.** November 2010 (Poster).

Lerma, NL and McCabe, LR. *Effects of glucosamine and chondroitin sulfate on cytokine markers in diabetic bone loss.* **National Conference of Undergraduate Research, Dominican University of California.** April 2007 (Lecture).

Lerma, NL and McCabe, LR. *Effects of glucosamine and chondroitin sulfate on cytokine markers in diabetic bone loss*. **McNair Scholar Symposium, Michigan State University.** August 2006 (Lecture).

Lerma, NL and Jayaraman, RC. *Effects of Frappier Acceleration Training Program on adolescent athletes.* **National Conference for Undergraduate Research, University of North Carolina – Asheville.** April 2006 (Lecture).

Lerma, NL and Jayaraman, RC. *Effects of plyometric, sprint, and agility training on skill related components of athleticism.* **American College of Sports Medicine Conference, Michigan Conference.** February 2006 (Lecture).

SERVICE

Academic committees and professional participation:

Course development committees

University of Wisconsin-Milwaukee

- KIN 290: Health & Wellness as We Age, Department of Kinesiology and Center for Aging and Translational Research (Summer 2017).
- SWK 300: Aged to Perfection (Introduction to Aging), Center for Aging and Translational Research (Summer 2015).
  - *Promising Practices Award, Mathers Lifeway Institute (2017), Innovation Award, Leading Age (2017).*

Curriculum development committees

University of Wisconsin-Milwaukee

- Department of Kinesiology, Exercise Physiology Curriculum Review (Spring 2017).
- Center for Aging and Translational Research, Graduate Certificate in Applied Gerontology (Summer 2014).

Ad-hoc manuscript reviewer

- Medicine and Science in Sports and Exercise.