THE INFLUENCE OF STRUCTURED, LONG TERM EXERCISE ON OBJECTIVELY MEASURED DAILY ACTIVITY IN OLDER ADULTS

By

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To my parents, late grandfather, family, and friends

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3MSE	Modified Mini-Mental State Examination
ADLs	Activities of Daily Living
CHAMPS	Community Health Activities Model Program
cm	Centimeter
DMAQC	Data Management and Quality Check
ECG	Electrocardiogram
G	Gravity
g	Grams
HE	Health Education
HLPA	High Light Physical Activity
HMPA	High Moderate Physical Activity
Hz	Hertz
IADLs	Instrumental Activities of Daily Living
kg	Kilogram
LIFE	Lifestyle Interventions and Independence for Elders
LIFE-P	Lifestyle Interventions and Independence for Elders-Pilot
LLPA	Low Light Physical Activity
LMPA	Low Moderate Physical Activity
LPA	Light Physical Activity
MB	Megabytes
MedRA	Medical Dictionary for Regulatory Activities
m	Meter
METs	Metabolic Equivalents
min	Minute

MMD	Major Mobility Disability
mmHg	Millimeters of Mercury
MVPA	Moderate to Vigorous Intensity Physical Activity
NHANES	National Health and Nutrition Examination Survey
PA	Physical Activity
RCT	Randomized Controlled Trial
RPE	Rating of Perceived Exertion
SB	Sedentary Behavior
SBRN	Sedentary Behaviour Research Network
SD	Standard Deviation
SPPB	Short Physical Performance Battery
TPA	Total Physical Activity
US	United States
VO_2 Max	Maximal Oxygen Consumption

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While exercise, defined as moderate-to-vigorous intensity physical activity (MVPA), has been observed to provide substantial cardiometabolic benefits in older adults, this subpopulation of US adults aged 70 years and older remains the most physically inactive. Previous literature has consistently observed physical inactivity to predict adverse health outcomes, such as physical disability, which leads to increased risks in morbidity and mortality. Thus, large-scale intervention studies such as the Lifestyle Interventions and Independence for Elders (LIFE) study have developed exercise interventions which have been observed to delay physical disability and increase independence towards daily living. However, the effect of long-term exercise on daily lifestyle physical activity, especially those activities which require low amounts of energy expenditure and constitute most daily physical activity, remains unknown.

Sedentary behaviors, defined as waking activities which involve sitting or reclining and require ≤ 1.5 metabolic equivalents (METs), make up the most engaged activity level by US older adults. These sedentary pursuits have been identified as a potential health risk factor for age-related morbidities and mortality, independent of exercise participation. The second most engaged daily activity level, light-intensity

activity, has been independently associated with improved health markers in older adults and is defined as activities requiring between 1.5-3 METs. Yet, with the infusion of daily MVPA, the question remains whether attributes of these activity levels are influenced. In addition, hospitalizations -acute events which displace activity patterns- among older adults negatively affect daily lifestyle yet previous literature on the topic is sparse. Therefore, the intervening effect of hospitalizations on the association between exercise and daily activity accumulation is unclear, yet important to understand.

The LIFE study provides a unique opportunity to examine the effect of exercise and daily activity accumulation because it is the largest and longest physical activity intervention to date, which also collected objectively measured physical activity through accelerometry. Therefore, this study was to examine accelerometer-based patterns of activity and inactivity in terms of volume, intensity, and duration and how these variables were influenced by long-term moderate-intensity exercise. Additionally, the effect of exercise post hospitalization on daily physical activity, a novel and not well understood relationship, was examined.

CHAPTER 1
INTRODUCTION

Aging and Public Health

The population across the world is aging due to increases in lifespan (22). In 2014, the World Health Organization projected that the amount of adults 60 years and older around the globe will double from 2000 to 2050 (85). Among this age group, those aged 80 years and older are projected to almost quadruple from 2000 to 2050. Also by 2050, the number of older adults is projected to outnumber children under the age 14 years old (85). In the United States, the population of older adults aged 65 years and older increased 24.7% from 2003 to 2013, reaching 44.7 million and is projected to more than double to 98 million in 2040 (109). Furthermore, the population of older adults 85 years and older is projected to rapidly increase from 6 million in 2013 to 14.6 million in 2040. This has become a public health challenge because older adults carry the highest burden of chronic disease, with a large proportion of individuals living with 2 or more chronic conditions (117). Consequences of living with chronic conditions lead to decreased functionality, threatening the ability to live independently (39). The National Center for Health Statistics estimated that a large portion of US older adults who reside in the community are dependent in either activities of daily living (ADLs) or instrumental activities of daily living (IADLs) (58). Due to the high vulnerability of physical disability in a rapidly growing US older adult population, one of the national public health objectives of the Healthy People 2020 goals is to increase the health, function, and quality of living among older US adults. To achieve this public health goal, prevention of physical disability and maintenance of independence is critical to reduce risks of illness, injury, institutionalization, and even death (10, 61, 84).

Physical Activity

Age-related physiological changes such as declines in aerobic capacity and reductions in muscle mass (sarcopenia) negatively affect basic daily functioning (35, 60). In regards to aerobic capacity, findings indicate that maximal oxygen consumption (VO_2 max) decreases approximately 5-15% per decade, while decreases in maximal heart rate, stroke volume, and muscle oxidative capacity affect oxygen delivery mechanisms which reduce oxygen consumption (118). Sarcopenia coupled with reductions in neural control have been associated with age-related reductions in muscle strength (21). Though these aging effects are inevitable, epidemiological studies provide evidence that a strong relationship exists between moderate-intensity exercise and functionality later in life (68). As age and disease occurrence increase, physical function tends to decrease (68). However, physical activity can attenuate the negative impact of aging and disease onset at different stages of functioning, preserving function and delaying physical disability (68). Moreover, a large amount of literature supports the beneficial effect of physical activity toward delaying all cause-, cardiovascular disease-, and cancer-related mortality among older adults (36, 63). In addition, a systematic review of the health benefits of physical activity reported a culmination of evidence supporting exercise to prevent coronary heart disease, type 2 diabetes, stroke, hypertension, and cancer (116). Furthermore, older adults engaging in purposeful physical activity have improved bone mineral density which reduces the risk of falls and fractures, improved cognition which reduces the risk of depression and dementia, and increased reserve capacity and aerobic fitness (46, 68, 116). Because of the large benefits gained by structured physical activity, the US Department of Health and Human Services published the first national guidelines in 2008, which state that some physical activity is better than none and that adults should engage in 150 minutes of moderate-to-vigorous intensity physical activity (MVPA) weekly (50, 83).

Sedentary Behavior

The Federal guidelines of 150 minutes of weekly MVPA among adults translates to approximately 20 minutes of MVPA per day or 2% (16-waking hours/day) of daily activity potentially committed to exercise. However, the scope of daily activity independent of MVPA is constantly changing with advancements in technology. Energy expenditure required for daily activity has decreased due to innovations developed to increase task automation, provide instant access to information, and ease effort when engaging in daily routines. These technological advances span across communication, transportation, occupation, and entertainment; which effectively changes the human environment towards promoting sitting-like behaviors (87). These sitting-like or sedentary behaviors (SBs) are distinct from lack of MVPA participation, emerging as an independent predictor of adverse health outcomes such as heart disease, metabolic syndrome, type 2 diabetes, cancer, hospitalization, and mortality (7, 49, 113). According to the Sedentary Behaviour Research Network (SBRN), SBs are defined as waking activities which require ≤ 1.5 metabolic equivalents (METs) and incorporate a sitting or reclining posture (103). Examples of SBs include television watching, computer use, vehicle driving, and video game playing. Older adults in the United States have been observed to engage in SBs for nearly 60% of waking hours, equating to around 7.7 hours/day (74). Not surprisingly, older adults in the United States are the most sedentary age group while also measured to have the lowest participation in MVPA (62, 74). Yet, controversy still remains towards understanding whether adverse health consequences are uniquely attributable to high SB engagement or if observed evidence can be accounted for by engaging in too little daily light/moderate/vigorous-intensity physical activity.

Light Intensity Physical Activity

Participation in SBs involves prolonged sitting or reclining activities, which have been linked poor health outcomes (87). Yet, emerging evidence supporting the relationship between breaks in prolonged daily SB and improved health markers has sparked interest in understanding accumulation of daily activity at different levels (51). Breaks in SBs incorporate a wide spectrum of activity ranging from light- to vigorous-intensity physical activity. Examples of activities at light intensities (1.5-2.9 METs) include walking slowly, making a bed, washing dishes, preparing food, and using light hand tools (1). Moderate-intensity physical activity includes activities such as walking at a brisk pace, heavy cleaning, mowing a yard, and bicycling, all of which require between 3.0-6.0 METs (1). Vigorous-intensity physical activity demands high energy expenditure (>6.0 METs) such as running, digging, and playing sports (1). In 2008, researchers published findings that higher breaks in sedentary activity were associated with improved metabolic risk profile (51). This is important because these breaks in SB occur differently between individuals and can impact health markers differently (30). While this research highlights the importance of accounting for accumulation of total daily SB, understanding the type of activity bouts in daily life independent of MPVA remains unclear. Interestingly, the body of evidence supporting the health benefits of light-intensity physical activity (LPA) is growing. One study found that higher time spent in LPA was associated with significantly lower 2-hour plasma glucose (52). The effect was observed among individuals with an average age of 53 years and independent of time spent in sedentary activity or MVPA. Another study found that high engagement in LPA in adults aged 60+ years old was negatively associated with arterial stiffening, a predictor of cardiovascular disease (40). In relation to physical function, researchers detected a positive relationship between higher durations of LPA with improved lower-extremity performance among community-dwelling Japanese older adults (86). In a cross-sectional analysis among mobility-limited older adults –a population at high risk for physical disability–, higher engagement in LPA was found to be associated with lower body mass index (4). In addition, older men in the same sample who spent more time in higher-intensities of light activity had higher grip strength. Another study examining mobility-limited older adults found a negative association between objectively measured duration in LPA and 10-year risk of hard coronary heart disease (34). The overall implications of these studies indicate favorable effects of LPA on health among an older adult population. This is particularly important among individuals in this age group who has been observed to engage in higher levels of daily LPA than those in other age groups.

Measuring Physical Activity

There is an emerging push to incorporate activity back into the daily lifestyle to combat the effects of physical inactivity and sedentary lifestyles. To do so, measuring daily physical activity patterns objectively is essential. Traditionally, questionnaires are used to assess daily activity such as the Community Health Activities Model Program for Seniors physical activity self-report assessment (CHAMPS) (56). This questionnaire was developed to capture physical activity by type and intensity among older adults. However, moderate correlations between self-report and objective measures were observed with activities such as leisure walking, volunteer work, and light gardening while low correlations were found with more sedentary behaviors such as television watching, reading, and riding in a car were detected. Since the validity of questionnaires is subject to biases in recall and social desirability (100), objective measurement tools were developed for implementation in physical activity research.

Directly observing activity or using tools which measure activity from a physiological standpoint remove bias relating to self-reported physical activity. However, correlations between direct observation methods versus self-reported measures in adults were low to moderate, and that the variability of these correlations was wide (102). Currently, free-living indirect calorimetry or otherwise known as doubly labelled water is considered the gold standard to measure energy expenditure through stable isotopes of oxygen and hydrogen evaluation from water intake and elimination (102). However, this method is expensive and imposes a significant time burden on the participant. Other measures which collect physiological responses to movement such as heart rate and pulmonary gas exchange devices are subject to confounding effects such as temperature, humidity, posture, and stress may confound the results (13).

Sensor monitors (e.g., pedometers and accelerometers) are portable and inexpensive compared to other objective measures. These devices excel at measuring duration of physical activity but do so in different ways (13). While pedometers are the least expensive of the sensor devices, they only collect daily step counts or volume of physical activity. Accelerometers collect movement in terms of acceleration which enables the collection of intensity, volume, and frequency domains of physical activity while also collecting daily step counts. Though both devices can be used in studies to determine associations and predictive factors, developers of large, longitudinal epidemiological studies or randomized control trials for physical activity are now turning to accelerometers to objectively measure physical activity.

Hospitalizations

Extant literature has shown physical inactivity to be a large contributor towards subsequent physical disability among older adults (110). Though exercise confers large health benefits, older adults remain the least physically active age group in the US (114). Physical inactivity can occur due to multiple reasons such as low fitness levels, inconvenience, exacerbations in pain, and comorbidity-related impairments (36). One major risk factor for physical inactivity is hospitalization among older adults (25). Despite the intentions of hospitalizations to mend ailments, unintended adverse health consequences tend to occur independent of the initial condition. Hospitalizations tend to impose a degree of immobility through bed rest and have been associated with declines in functionality (25). The interaction between aging and hospitalization effects have been observed to negatively impact muscle strength, aerobic capacity, respiratory characteristics, bone density, continence, and sensory systems (25). Among older adults 70 years and older, hospitalization is a strong risk factor for declines in ADL function, independent of the reason for hospitalization (24). Without a return to pre-hospitalization functional status, hospitalized older adults tend to shift into inactive lifestyles which accelerate the likelihood of being physical disability and losing the ability to be independent. However, little is known whether purposeful physical activity can reduce the risk of becoming hospitalized, and whether hospitalizations may affect the benefits of exercise on daily lifestyle activity in older adults.

Rationale

Understanding the distributions of daily physical activity and related determinants among the population of US older adults still remains unclear. This is particularly important among mobility-limited older adults who are at high risk of physical disability and loss of independence. Since the emergence of accelerometers and the ability to objectively capture daily routines of activity, we can now examine the influence of a long-term exercise intervention on daily lifestyle activity. In addition, the interceding effect of hospitalizations on the relationship of exercise and daily total activity is equally important due to the vulnerability of accelerated health declines in older adults. Since the goal of independence in free-living settings is critical to public health, the impact of exercise, defined as moderate-intensity physical activity for older adults, on daily activity must be understood. The interaction between exercise, daily lifestyle activity, and hospitalizations can be conceptualized according to Figure 1-1. While it is obvious moderate-intensity physical activity increases with the effect of exercise, we hypothesize that all other activity levels will improve (e.g., meaningful activity increases while SBs will decrease). This conceptual framework also captures the intervening effect of hospitalization on the association between exercise and daily activity. Figure 1-1 depicts that when hospitalizations occurs, the benefits of exercise on daily activity are negatively impacted, however the relationship between exercise and improved daily activity remain.

This study examined how long-term exercise affects daily activity characteristics and functionality among older adults with mobility impairments. The central hypothesis is that long-term exercise beneficially influences patterns of daily physical activity by frequency, intensity, and duration. More specifically, time spent in light-intensity is thought to increase while engagement in sedentary activities would decrease. Also, long-term exercise is hypothesized to reduce the impact of hospitalizations, events that negatively affect lifestyle and independence among a highly vulnerable population of older adults. With the rapid surge of accelerometer use in many physical activity interventions, daily activity can now be assessed in a variety of ways including duration, frequency, intensity, and accumulation. Exploring these characteristics of total daily physical activity will fill a knowledge gap on the longitudinal effects of long-term exercise on daily physical activity among older adults, a population which independent living must be maintained.

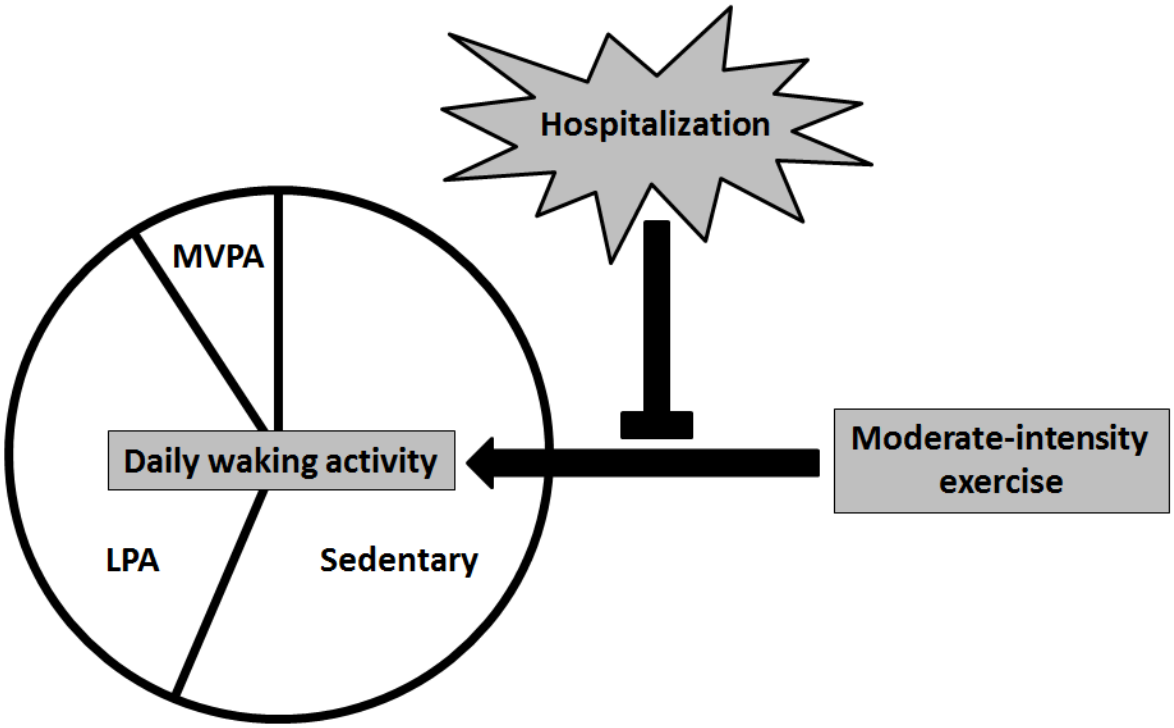

Figure 1-1. Conceptual framework of the interaction between moderate-intensity exercise, hospitalizations, and daily waking activity. Moderate-intensity exercise increases the time spent in other levels of physical activity intensities such as light-intensity physical activity (LPA) and moderate-to-vigorous physical activity (MVPA). Additionally, moderate-intensity exercise reducing time spent in sedentary activity. However, hospitalizations play an intervening role on benefits of chronic, moderate intensity exercise on daily waking activity.

CHAPTER 2
APPROACH

Overall Strategy

The goal of this proposal is to examine the effects of a long-term, moderate-intensity exercise on objectively measured physical inactivity and activity levels among older adults with mobility impairments. Long-term exercise has been observed to reduce morbidity and mortality while improve quality of life (83). This is important in older adults, a population already at risk for a multitude of adverse health conditions. However, the effects of long-term exercise tailored for mobility-limited older adults on total daily activity are not well known. This study compared the effect of a 2-year exercise program to a health education program using objective accelerometer metrics of physical inactivity and activity. Because older adults are at high risk of adverse health events, the role of hospitalizations was examined between the relationship of exercise and accelerometry measures of daily activity.

Analytic Sample

This analysis utilized the Lifestyle Interventions and Independence for Elders (LIFE; n=1,635). The LIFE study is a multi-center, single-blinded, parallel randomized controlled trial (RCT) which evaluated the efficacy of a structured, long-term exercise program (PA; average of 2.7 years) in reducing the risk of major mobility disability (MMD) as compared to a health education program (HE) among older adults (89). The inability to walk a quarter mile (400 meters) within 15 minutes without sitting, leaning against a wall, or the assistance of another person or walker was utilized as the definition of MMD. In addition, secondary outcomes such as cognition, falls, self-reported disability and cost-effectiveness, and tertiary outcomes including physical performance, sleep-wake disturbances, dyspnea and ventilatory capacity, and hospitalizations or cardiopulmonary events were examined (32). The LIFE study examined whether PA prevented MMD in order to address the emerging public health issue of continually increasing rates of physical disability in a majorly sedentary and aging US population. Currently, the LIFE study is the longest and largest physical activity RCT focused on functional outcomes (72).

To accomplish the goals of this study, eight participating centers across the US participated in recruitment and data collection. These centers included the University of Florida at Gainesville and Jacksonville, Florida; Northwestern University at Chicago, Illinois; Pennington Biomedical Research Center at Baton Rouge, Louisiana; University of Pittsburgh at Pittsburgh, Pennsylvania; Stanford University at Stanford, California; Tufts University at Boston, Massachusetts; Wake Forest School of Medicine at Winston-Salem, North Carolina; and Yale University at New Haven, Connecticut. This recruitment approach aimed to ensure a representative sample of US older adults highly susceptible of MMD within rural, suburban, and urban communities. The LIFE study accomplished this by recruiting within a 21-month phase using screening methods to target adults aged 70-89 years old, sedentary, at risk of mobility disability yet able to walk ¼ mile, without any adverse health problem which may exacerbate during increased physical activity, and were willing to be randomized to either the intervention or health education.

These screening criteria was applied in order to recruit older adults who did not engage in structured and planned physical activity, who were at high risk of mobility disability and willing to participate in the LIFE trial. The decision to recruit adults aged

70-89 was because this segment of the US represented one of the fastest growing in the US (70). Additionally, this subpopulation is at high risk of illness, institutionalization, reduced quality of life, and mortality (10). Older adults with a sedentary lifestyle were operationally defined as self-reporting engaging in < 20 minutes per week of regular exercise and reporting ≤ 125 minutes per week of MVPA on the 18-item CHAMPS physical activity questionnaire. Sedentary older adults were important to recruit because highly active older adults who already engage in chronic physical activity may not benefit from a physical activity intervention. In addition, highly active older adults may not be at high risk of mobility disability. This is typically defined as scoring less than a 10 (of 12) on the Short Physical Performance Battery (SPPB) (48), a test of physical performance. Additionally, the LIFE study recruited a subset of participants who scored less than an 8 (45% of the sample) to enhance the total sample of participants at high risk of mobility disability. Also, eligibility required participants to complete a 400 meter walk test within 15 minutes without any assistant devices, or the help of another person. Lastly, participants had to be willing to accept randomization into either the intervention group (PA) or the comparison group (HE).

Exclusions to the LIFE study largely encompassed criteria which compromised safety of the participant. Specifically, those who had speech problems, had a diagnosis of schizophrenia, other psychotic disorders, or bipolar disorder, reported consumption of more than 14 alcoholic drinks per week, were unable to walk across a room, had no major cognitive impairment below education and race-specific norms, had severe arthritis, underwent cancer treatments within the past 3 years except for non-melanoma skin cancers and those cancers with excellent prognosis, had lung disease requiring corticosteroids or supplemental oxygen, had cardiovascular diseases, had Parkinson's disease or other progressive neurological disorders, had renal disease requiring dialysis, had chest pains/shortness of breath/other safety concerns during the 400 meter walk, had medical/psychiatric/behavioral concerns that may interfere with study participation, had illness severity which yields life expectancy to less than 12 months, and had other clinical judgements concerning safety or noncompliance of study procedures. Other exclusion criteria included not giving informed consent, not willing or unable to be randomized, plans to relocate outside of study area within the next 2 years or plans to be out of the study for 6 consecutive weeks during the year, nursing home residence, a participant of the LIFE-P study (pilot study), or another member of the household was a participant of the LIFE study. Eligible individuals may experience temporary exclusion criteria which must be managed before participation. These included uncontrolled hypertension defined as systolic blood pressure greater than 200 mmHg and/or diastolic blood pressure greater than 110 mmHg; uncontrolled diabetes with recent weight loss, diabetic coma, or frequent insulin reaction; myocardial infarction, major heart surgery, deep vein thrombosis, pulmonary embolus, stroke, hip fractures, hip or knee replacements, or spinal surgery within the past 6 months; ECG determined conduction disorder, uncontrolled arrhythmia, new Q waves or ST-segment depressions; going through physical therapy or cardiopulmonary rehabilitation; or enrolled in another trial focused on lifestyle or therapeutic intervention.

Accelerometry

The LIFE study collected measures of daily physical activity and inactivity using the ActiGraph™ GT3X activity monitor. This is a lightweight (27 g), and portable (3.8 cm x 3.7 cm x 1.8 cm), hip-worn device which collected movement in terms of acceleration.

As the device measured accelerations, it recorded within the magnitude range of 0.05 to 2.5 G's, digitizing the analog signals at a rate of thirty times per second (30 Hz). The digitized signal passed through a band filter which limited the frequency range to 0.25 to 2.5 Hz to eliminate non-human motion. Each sample was summed over an epoch, defined as a user-specified interval of time. Preprocessing the accelerometer data outputs summarized activity counts which are comparable between individuals. The GT3X is capable of storing over 3 weeks of data on 16 MB of flash memory. This type of memory retained stored contents even if the device lost power. The device was built to house a rechargeable Lithium Polymer battery. When full charged, the battery was able to provide power for up to 20 days without recharging. The ActiGraph™ GT3X monitor was primarily chosen for the LIFE study because it has been widely used in previous research studies (23, 65, 74, 114). Further, this type of accelerometer has been effective to capture physical activity patterns in older adults (23).

All participants randomized to the LIFE study were asked to collect accelerometry at baseline and at 6-, 12-, and 24-month follow-up visits. The study coordinators explained the accelerometry procedures to each participant, including how to adjust and wear the elastic belt which held the accelerometer. Then, the participant was monitored as they self-attached the device onto the hip. The participant was instructed to wear the device before and during the 400 meter walk test, and then for the remainder of the day. Then instructions for the participant were to wear the accelerometer for the next seven days while performing normal daily routines of activity. Participants were given written instructions to not wear the accelerometer during sleep times and water-related activities such as bathing, showering, and swimming.

Additionally, participants were given a picture depicting how the device should be placed when it was not worn. On the second or third day of data collection, the participant was called to assess if there were any additional questions and how they were doing. The participant was also reminded to either mail the accelerometer back with a pre-addressed and stamped envelope given during the clinic visit or return the accelerometer to the clinic after the seven-day accelerometry collection period. Once the study staff received the accelerometer, the data was downloaded and evaluated for at least 5 days of 10+ hours of time where the monitor was worn and the participant was awake. If there was no data, study staff asked the participant to wear the monitor again for another 7 days on a different accelerometer or the same accelerometer if the cause of collecting no data was determined to be an uncharged battery. Valid accelerometry data was transferred to the Data Management and Quality Check (DMAQC) committee. Study staff accomplished this by uploading the accelerometry data to the LIFE website. Standardized protocols specific to the clinical sites were developed to track accelerometers, repair records, and how accelerometers were returned to the clinics.

Tri-axial activity monitors collect data on three planes of space or axes (Figure 2-1). While LIFE accelerometers collected on three-axes, only data collected on the vertical axis was processed. The vertical axis data have observed to be closely correlated with locomotion and stepping movements through numerous validity studies (37, 73). The LIFE activity monitors were set to collect data at a rate of 30 Hz per second. Each sample was then expressed as an activity count, a quantitative measurement of movement over time. The hip-worn accelerometers continuously collected data whether it was on the body or not. Participants were given a visualization which depicted how to orient the device when it was off the hip. Six or more seconds in this orientation assisted investigators to estimate whether the device was not worn, where Z-axis offset angle in relation to the device's inclinometer was < 22º. However, since the X-axis (vertical) data was used to examine activity, validated non-wear vertical axis algorithms were used to detect and remove non-wear times. The LIFE study used the criteria determined by Choi and colleagues (18), scanning for at least 90-minute intervals of consecutive zero counts. The algorithm also built in a scanning up-stream and down-stream window of 30 minutes to identify allowances of 2-minute artifactual non-zero counts. Thus, any zero counts not meeting the Choi criteria was considered as valid non-movement and non-zero counts not considered artifactual movement was valid movement, otherwise known as valid wear time.

The LIFE Accelerometry Working Group and DMAQC found 1,411 of 1,635 participants at baseline had satisfactory accelerometry data. This was defined as participant data successfully received, imported into the LIFE database, verified by study staff, and met the 10-hour daily wear time minimum criteria. This study further refined the inclusion criteria to only those with 3+ days of 10+ hours of daily wear time. Though there is missing accelerometry data at baseline, we assumed data is missing completely at random. However, we examined differences between participants with and without valid accelerometry data at baseline across age, sex, race/ethnicity, education, body mass index, cognition, and walk speed (Table 2-1). There was > 95% missing values for self-reported race/ethnicity and education for those with missing accelerometry data but across all factors but, in general, there were no differences (Table 2-1). Table 2-2 shows accelerometry collected at three additional time points (6-, 12-, 24-month follow-ups) where missing data at these follow ups was < 10% (except for the 24-month visit; 10.5%).

Accelerometers of the LIFE study collected 1-second epochs of activity or inactivity and generated vast amounts of data. To thoroughly explore and interpret these large datasets, the study derived and analyzed various novel variables of accelerometer data of physical inactivity and activity. Table 2-3 describes characteristics of accelerometry that were generated by the investigator. The most traditional variable of accelerometry is volume or the time (e.g. minutes, hours, and days) spent within a specific activity or inactivity intensity range. This was generally reported as a daily average and compared between groups. Accumulation of accelerometry data was calculated as bouts of activity or inactivity, defined as events of consecutive minutes registering within a specified intensity range. For example, bouts of 10+ sedentary minutes are events with at least 10 or more sequential minutes within activity intensities below 100 counts per minute. Time spent in these bouts reveal a type of activity/inactivity accumulation throughout the day. Intensity of accelerometry gives an approximation of how much energy is being expended by the body. Intensity was examined in two different ways: average activity intensity of total daily accelerometry wear time, and absolute intensity thresholds. Average activity intensity provides an approximate measure of individual daily activity yield, where absolute intensities were pre-determined using previous literature (23, 37, 73). Time spent in these thresholds will be evaluated and combines both volume and intensity.

Table 2-4 presents accelerometer cut-points used to capture the range of intensities across physical activity. Physical inactivity, labeled sedentary activity, was explored at an < 100 counts/minute. Physical activity was considered as 100+ counts/minute, broken up into light- (low & high) and moderate-intensity (low & high) physical activity. Total physical activity (TPA) was also examined, defined as a combination of all activity levels 100+ counts/minute. This study explored traditional thresholds of intensity levels which have been typically used in national studies such as the National Health and Nutrition Examination Survey (NHANES) study aimed to target all adult age ranges. Also, lowered cutoff levels was explored to better understand the impact of exercise on activities which require lower intensity accelerations generally generated by older adults. This novel approach was possible because of the richness of the LIFE data and the large sample size of participants providing valid accelerometry. To our knowledge, only one study using LIFE data has used lower light activity variations (100-499 & ≥ 500 counts/minute) to examine the relationship with cardiovascular disease prediction (34), but effects of exercise and hospitalization on these accelerometer measures remain unclear.

Hospitalizations

Accelerometry in relation to the intervening effect of hospitalizations on the benefits of exercise focused within time intervals characterized as baseline to 6 month, 6 to 12 month, and 12 to 24 month intervals. Hospitalizations were collected via an outcome events questionnaire where participants were asked whether a hospitalization event occur since the last assessment period. Previous literature has validated the use of self-reported hospitalizations as way to ascertain the occurrence of these events (6, 55, 106). The outcome evaluators were blinded to intervention assignment. Medical record technicians and adjudicators could also identify hospitalizations while reviewing medical records. Additionally, participants were asked to notify study staff (unmasked) about any hospitalization or serious illness in between follow-up interviews where events were reported via adverse event forms.

Only hospitalizations reported to masked staff at the scheduled follow-up visits were considered for this dissertation. This was to equalize the group comparisons because the PA intervention had more contact with unmasked interventionists who could report serious adverse events. Characteristics of hospitalizations were assumed to be equal between intervention groups but were examined by participants hospitalized, number of hospitalizations, and days hospitalized across intervention group. Though we assumed the number of hospitalizations >1 day are equal between intervention groups but baseline participant characteristics were examined. A time-varying hospitalization variable was derived by calculating whether participants had any hospital days during each time interval. Because hospital days are positively skewed, we binned hospital days into short (1-3 days) and long (4+ days) and then created three categories: no hospitalizations, short cumulative hospital duration, and long cumulative hospital duration. This was used at the primary predictor of changes in accelerometry. Hospitalization events were also examined for any potential overlap with accelerometer collection periods.

Interventions

The main predictor for this dissertation is a long, moderate-intensity physical activity intervention. This PA intervention was developed from the theory of a social cognitive model of acquisition and maintenance of health behaviors (2). This model considers health behavior as acquirable and maintainable through behavioral, cognitive, physiological, and environmental conditions. This concept was coupled with strategies developed from the Transtheoretical Model, a conceptualization of intentional behavioral change (94). These strategies involve raising awareness of health behavior and using cognitive processes to first prepare, stimulate, and then reinforce, and manage physical activity. These approaches were tailored as needed and applied at an individual level by study staff.

The goal of the PA intervention was to administer 150 minutes/week of moderate-intensity physical activity consisting of aerobic, strength, flexibility, and balance training. Since the intervention was tailored toward the individual's physical fitness level, the PA intervention was modifiable towards illness, injury, and physical symptoms. Walking was the primary component of the PA intervention, due to its ease of administration and widespread popularity among US adults (108). Each session involved a brief warm-up and cool-down period, and flexibility exercises were performed after each bout of walking. Strengthening exercises targeting lower extremity muscles were performed using variable ankle weights. Balance training was combined with the walking and strengthening exercises. For the first 2-3 weeks of training, participants were introduced to lighter-intensity physical activity and then progressively trained at moderate-intensity physical activity. To achieve moderate-intensity physical activity, ratings of perceived exertion were used measured by the Borg's scale (8, 9). This scale ranged from 6 to 20, where participants were asked to achieve an intensity of 13 (perceiving activity to be "somewhat hard"). Participants were discouraged to exercise at levels approaching an intensity of 15 ("hard") or dropping to ratings of 11 ("fairly light") or below. These levels were maintained during walking exercises. During strengthening exercises, 2 sets of 10 repetitions were performed at intensities of 15 to 16 using the Borg's scale.

At baseline, participants were randomized to either the PA or HE intervention group. The purpose of the HE intervention was to control for the interaction between the study staff and participant and other secular/seasonal effects which could influence outcomes of interest. Staff contact by intervention group is detailed in Table 2-5. The purpose of the HE intervention arm was to provide a control measurement to the PA intervention without affecting the study outcomes. The HE intervention was an educational program which provided information relevant to older adults. Examples of the topics include discussing the healthcare system, traveling safely, preventive services, and how/where to gather reliable health information. Combined with the educational lectures, an instructor led a 5- to 10-minute upper extremity stretching plus relaxation component administered at each session.

Covariates

There are a multitude of baseline characteristics which may be examined to assess differences based on hospitalization. Sociodemographic factors included sex, race/ethnicity, income, education, and marital status. Behavioral factors including smoking, alcohol use, and body mass index were examined. Self-reported comorbidities and hospitalizations were also assessed. However, the strength of using the LIFE study is the randomization of participants into intervention groups stratified by clinical site and gender. This was assumed to eliminate any baseline differences between intervention groups. For all aims, accelerometer wear time and baseline accelerometer time were used as a covariate. For aims 1 and 2, sex and clinical site were added (randomization factors), while aim 3 will include sociodemographic, behavioral, medical, and accelerometer covariates.

Table 2-1. Baseline participant characteristics by accelerometry collection status

	Accelerometry		
	Valid (n = 1,341)	Invalid (n = 98)	Missing (n = 196)
Age in years, mean (SD)	78.7 (5.3)	79.4 (5.2)	79.6 (4.9)
Female, n(%)	892 (66.5)	67 (68.4)	139 (70.9)
Non-Hispanic White, n(%)	1,017 (75.8)	69 (70.4)	6 (3.1)[b]
≥ College education, n(%)	847 (63.2)	62 (63.3)	5 (2.6)[b]
Body mass index (kg/m^2), mean(SD)	30.3 (6.0)	29.5 (6.2)	33.1 (5.4)
Modified Mini-Mental State Examination score[a], mean(SD)	91.7 (5.4)	89.3 (5.3)	88.7 (4.7)
400 meter walk speed (m/sec), mean(SD)	0.8 (0.2)	0.8 (0.2)	0.8 (0.2)

[a] score range: 0-100 where higher scores indicate better performance

[b] factor has > 95% missing values

Table 2-2. Accelerometry data collection by visit

	6-month (n=1,556)	12-month (n=1,510)	24-months (n=1,417)
Valid, n(%)	1,303 (83.7)	1,310 (86.8)	1,164 (82.0)
Invalid, n(%)	118 (7.6)	105 (7.0)	104 (7.3)
Missing, n(%)	95 (6.3)	95 (6.3)	149 (10.5)

Table 2-3. Accelerometry characteristics

Type	Outcomes	Description
Volume	Total time, minutes	Time within specific activity/inactivity intensity range
Accumulation	Time spent in bouts, minutes	Time spent within specific activity/inactivity intensity range for at least the amount of consecutive minutes specified
Intensity	Average activity, counts/min	Time spent in average counts/min across total daily accelerometry wear time
	Absolute threshold, counts/min	Time spent in pre-determined (sedentary, total activity, light, lifestyle, moderate intensity) count/min thresholds

Table 2-4. Accelerometry cut-points denoting intensity ranges

Type	Intensity	Counts/minute
Physical inactivity	Sedentary	<100
Physical activity	Low light	100-759
	High light	760-1,040
	Low moderate	1,041-2,019
	High moderate	2,020+

Table 2-5. Staff contact by intervention group

Physical activity group		
Week	Center-based	Home-based
Adoption: week 1 to 52	2 times a week	1 time/week (week 1-4) 2 times/week (week 4-8) Up to 3-4 times/week (week 8-52)
Maintenance: week 53 to end	2 times a week	Up to 3-4 times/week
	Successful aging group	
Week	Center-based	Telephone contact
Adoption: week 1 to 26	1 time a week	After one missed visit, contact was made to problem-solve barriers to attendance
Maintenance: week 27 to end	Once a month, while offered twice a month	After first session missed, contact was made

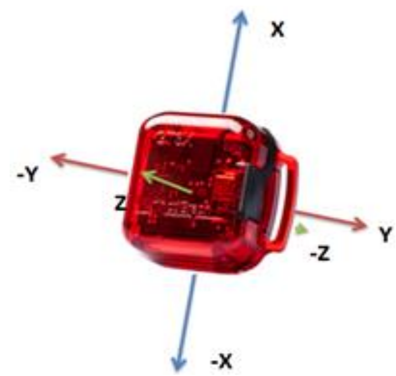

Figure 2-1. Tri-axial accelerometer. The vertical plane is the x-axis; medial-lateral is the y-axis; and anterior-posterior is the z-axis.

CHAPTER 3
EFFECTS OF A LONG-TERM PHYSICAL ACTIVITY PROGRAM ON SEDENTARY TIME IN OLDER ADULTS

Background

Excessive daily sedentary behaviors (SB) among older Americans aged ≥70 years of age has recently emerged as a national public health issue, averaging approximately 9 hours/day or 66% of daily waking time in SB (74). SB, characterized as requiring ≤ 1.5 metabolic equivalents (METs) while sitting or reclined (103), include lying awake quietly, watching television, using a computer, and driving a vehicle. Epidemiological evidence suggests these behaviors are associated with adverse health outcomes such as cardiovascular disease, diabetes, and the metabolic syndrome, regardless of participation in physical activity (PA) (3, 53, 54). Coupled with aging, the increased risk of these negative health conditions can adversely affect independence later in life (39, 110).

Beyond total sedentary time, the manner in which sedentary time accumulates is also important to health. Daily accrual of long, uninterrupted sedentary bouts is linked to poorer cardiometabolic health and death when compared to patterns displaying frequent breaks from SB (5, 14, 30). Recently, patterns of sedentary time were examined in a large sample of US middle-aged and older adults (45 years and older); the results suggested that almost half of total daily sedentary time was accumulated in continuous bouts of 30 minutes or greater (27). This growing body of literature supports further study of ways to link PA guidelines with strategies to reduce sedentary time, particularly in regard to its accumulation patterns.

A large amount of evidence suggests that daily participation in moderate to vigorous intensity physical activity (MVPA) delays risks of mortality, morbidity, and disability among adults ≥65 years old (116). Additionally, this age segment has the lowest participation of MVPA among the entire US population, which exacerbates the public health impact (114). To address this issue, the Lifestyle Interventions and Independence for Elders (LIFE) randomized trial was conducted to compare structured, moderate intensity PA and health education (HE) interventions among older adults (70-89 years old) with functional limitations to reduce the risk of major mobility disability (32). The main result demonstrated a significant increase in moderate intensity PA and mobility benefit (89), but it was not clear whether patterns of daily sedentary engagement were also changed in the process.

The LIFE study provided a unique opportunity to address this knowledge gap with the collection of objective daily activity and sedentary time using accelerometers over 24 months. The primary aim of this paper was to compare differences in sedentary time between PA and HE. It was hypothesized that a 24-month PA intervention would lead to a decrease in sedentary time compared to HE. The second aim of this paper was to determine whether changes in sedentary time were associated with changes in physical function. It was hypothesized that increased sedentary time would be associated with declines in physical function, independent of intervention assignment.

Methods

Trial Design and Participants

Details of the design and methods of the LIFE study (32) and our primary results (89) have been published elsewhere. In summary, this was a Phase-3, multicenter, investigator-blinded, randomized controlled trial to test whether a long-term moderate intensity PA intervention would reduce the risk of major mobility disability as compared to HE. The trial included 1,635 mobility-limited men and women, aged 70-89 years old.

Mobility limitation was defined as scoring <10 (out of 12) on the Short Physical Performance Battery (SPPB) (48), but able to walk 400 meters within 15 minutes without sitting, leaning against a wall, or getting any assistance. Participants were eligible for the trial if they were sedentary (self-reported spending <20 min/week in the past month getting regular PA and <125 min/week of moderate intensity PA) and had no major cognitive impairment (score >1.5 standard deviations below education- and race-specific norms on the Modified Mini-Mental State Examination [3MSE] (111)). Participants were recruited from eight field centers across the nation within a 21-month period, where the primary recruitment strategy was targeted community mass mailings. The LIFE study was registered with www.clinicaltrials.gov before trial enrollment (NCT01072500). The institutional review boards approved the study protocol at all participating sites and is available on request at https://www.thelifestudy.org/public/index.cfm. Written informed consents were obtained from all participants.

Interventions

At baseline, participants were randomized to either the PA intervention or HE program. Both arms promoted behavioral change based on principles of social cognitive theory and strategies formulated around the Transtheoretical Model (e.g., raising health behavior consciousness, preparing for action, and providing support for maintenance through cognitive approaches) (93). The PA intervention consisted of an individually tailored plan to initiate and maintain 150 min/week of moderate intensity PA. The intervention included aerobic exercise consisting of a walking regimen in parallel with lower extremity strength, flexibility, and balance training. The PA program format consisted of 2 center-based sessions/week and 3-4 home-based sessions/week. To achieve moderate intensity PA, the Borg's Rating of Perceived Exertion Scale (RPE) was used (8). This scale ranges from 6 to 20, where participants were asked to achieve an intensity of 13 (perceiving activity to be "somewhat hard"). During strength exercise, 2 sets of 10 repetitions were performed at intensities of 15 to 16 using Borg's RPE scale. The HE group participated in workshops specific to health and well-being for older adults, with intentional avoidance of topics related to PA. The program includes a 5-10 minute session of upper extremity stretching or flexibility exercises. The HE arm was expected to meet weekly during the first 26 weeks of the intervention and at least once monthly thereafter.

Accelerometer Measurements

Objective daily PA and sedentary time were collected via accelerometers at the baseline, 6, 12, and 24 month visits. The accelerometer (Actigraph™ GT3X) measures accelerations within a magnitude range of 0.05 to 2.5 units of gravity. The analog signal was digitized at a rate of 30 times per second (30 Hz) and passed through a band filter that eliminated non-human motion. Each sample was summed over 1-second epochs and converted to an activity count. An activity count is a unit-less digitized quantity of movement expressed over time (i.e., activity counts/minute). The GT3X is capable of collecting and storing data up to 20 days on a single charge of battery. Participants were asked to wear the accelerometers on their right hip at all times for at least 7 consecutive days except during sleep and water-related activities (e.g., swimming or showering). Though the accelerometer collected tri-axial data, only data collected from the vertical axis were processed. Vertical axis accelerometry collected from the hip has been validated to assess locomotion-type movements in a number of studies (37, 73).

Sedentary Variables

The accelerometer continuously logs movement and non-movement so there is no distinction between wear and non-wear time. To distinguish between the two, PA data were first processed for valid wear time periods using a non-wear algorithm developed by Choi and colleagues (18). This algorithm was chosen because it improves on the NHANES algorithm to detect low activity levels and high SB, particularly in those who are expected to have prolonged bouts of sedentary time (114). Briefly, data were binned into 1-minute epochs and scanned for consecutive zero counts lasting at least 90 minutes. Two-minute intervals for non-zero counts within 30-minute upstream and downstream zero count windows were allowed as an exception; any other non-zero count registered by the accelerometer was considered wear time. Additionally, outliers were identified (minutes where activity counts exceeding 10,000, 3,500 counts over median of the 2nd highest activity counts/min across all days, or 1,000 counts over the 2nd highest activity count/min of the same day) and were classified as outliers and re-labeled as non-wear time. Additionally, the data were visually inspected for isolated patterns or unexplainable phenomenon (e.g., maintaining the same activity level for extended periods of time at extremely high levels of activity), which were removed ad-hoc. In total, 34 days from 18 participants were removed: 1 day from baseline, 7 at 6 months, 5 at 12 months, and 21 at 24 months.

Each valid wear minute was labeled as sedentary if counts summed to <100 over 1 minute (114). Accumulated sedentary time was characterized in three ways. First, bouts of sedentary time were calculated as consecutive sedentary minutes of at least 1+, 10+, 30+, or 60+ minutes. Second, an individualized measure of sedentariness was derived as a bout length at which 50% of total daily sedentary time was accumulated (50% bout length). This was done by creating a regression model for each participant as follows: % sedentary time = bout length + (bout length)^2. The equation was solved for each person to predict bout length at 50% sedentary time. Third, sedentary breaks were calculated as an interruption of consecutive sedentary minutes where one sedentary minute transitioned to a non-sedentary minute (>99 counts/min).

Physical Function Measures

Measures of physical function considered in this analysis were walking speed (meter/second) and lower-extremity physical performance measured at baseline and 6, 12, and 24 months. Walking speed was assessed during a 400-meter walk where participants were asked to complete 10 laps on 20-meter course at their usual pace. Participants were allowed to stop and take a break for up to 1 minute without sitting during the assessment. If a participant stopped before the 10 laps were completed, the distance traveled was measured. Walking speed was calculated as distance/time in meters/second. The SPPB was used to assess physical performance using balance, usual gait speed, and chair stand tests. Each component was scored from 0 to 4, with higher scores indicating better performance. The component scores were summed to yield a total score from 0 to 12, where 12 was the highest attainable score of physical performance.

Statistical Analysis

Only participants with valid accelerometry (10+ hours/day of accelerometry for at least 3 days at all time points) were included in this analysis. The distribution of the sedentary bout data were evaluated for normality prior to conducting analyses. The time spent in 1+ minute bouts had a large range and was normally distributed. Baseline characteristics and total daily average wear time metrics of participants with valid data were examined by intervention. Mean differences in sedentary outcomes between intervention arms were estimated using linear mixed-effects modeling. Visit (time) was treated as a repeated factor, and the baseline sedentary-specific metric, age, visit, and wear time were included as fixed effects. Factors used to stratify randomization (sex and clinical site) were also included in the model as fixed effects. The association between changes in sedentary time and changes in physical function were evaluated after pooling the effects across intervention groups. Individual slopes for sedentary measures were derived from mixed effects linear regression over four time points while adjusting for wear time at each measurement. Individual slopes for physical function (400 meter walk speed and SPPB score) were calculated similarly. Because there are multiple determinants of changes in physical function, we included in exploratory analyses the following covariates to understand the independent effect of changes in each sedentary metric: age, sex, intervention assignment, clinical site, race, comorbidity index >2, education level, 3MSE score, self-reported depression, body mass index (kg/m^2), reported having smoked 100+ cigarettes during lifetime, and daily activity (accelerometer minutes registering 760+ counts/minute). Additionally, we included an interaction term of baseline SPPB category (<8 vs. 8+ score as the reference) by sedentary change to examine effect modification by baseline functional status. Accelerometer data were processed using R (www.r-project.org) (18, 115) and statistical analyses were performed in STATA v13 (STATA Corp.).

Results

Population Sample

Of the 1,341 participants from whom we obtained valid accelerometry data at baseline, 669 participants were randomized to the PA group and 672 randomized to the

HE group (Figure 3-1). Baseline participant characteristics described in Table 3-1 were similar between groups. Average age was 78.7±5.3 (SD) years old, 66.5% were women, 75.8% were Non-Hispanic white, mean body mass index (kg/m2) was 30.3±6.0, 44.4% had an SPPB score < 8, and 42.3% had a 400-m walking speed < 0.8 meter/second. Also, average wear time (837.0±111.0 minutes/day) and total daily sedentary time (1+ min bouts; 646.8±116.4 minutes/day) were similar between groups. On average, 488.3±131.8, 296.0±132.7, and 145.4±102.9 min/day were spent in 10+ minute, 30+ minute, and 60+ minute sedentary bouts, respectfully. Those without valid accelerometry data (n = 294) were similar in regard to age (79.6±5.0 years old) and sex (70.1% women) as compared to the sample who had valid accelerometry data.

Sedentary Variables by Intervention

Changes in daily sedentary variables over 2 years by intervention group are illustrated in Figure 3-2. While there was an overall 0.8±0.1 minutes/day increase per month in total daily sedentary time within the sample (p<0.001), the PA group experienced an overall reduction of 8.8±2.9 total sedentary minutes/day compared to the HE group over 24 months (p=0.002). These group differences appeared to occur within the first 6 months and were maintained throughout the study (p=1.00 for intervention group difference at 6 months vs. 24 months). Daily sedentary time in 10+, 30+, and 60+ minute bouts increased over time (1.4±0.1, 1.6±0.2, 1.3±0.1 minutes/day, respectively; p<0.001 for all) where significant intervention differences were detected for 10+ and 30+ minute bouts (PA vs HE: -11.5±3.9 minutes/day, p=0.003 & -9.3±4.1 minutes/day, p=0.02, respectively). Average 50% bout length at baseline was 28.1±13.2 minutes and increased 0.2±0.03 (p<0.001) minutes monthly, with no significant differences between intervention groups (p=0.25). Daily average sedentary breaks taken during baseline was 70.8±17.9 and decreased by 0.2±0.02 times per month, with no significant intervention differences detected ($p=0.90$).

Associations with Change in Physical Function

Analyses were conducted to examine individual changes in physical function and sedentary variables by baseline functional status category (i.e., SPPB <8 vs. 8-9). Results in Table 3-2 demonstrate that sedentary time patterns increased whereas sedentary breaks declined over time. These changes were greater among those with low baseline function, except for 1+ minute bouts ($p=0.08$). With regards to physical function, walking speed decreased over time (-0.002±0.003 meter/second per month) and this decrease was greater in those with lower compared to higher function ($p<0.001$). SPPB scores increased in the higher function group (0.04±0.03 SPPB units per month), but declined in the lower function group (-0.01±0.04 SPPB units per month). Figure 3-3 illustrates correlations between standardized changes in sedentary variables with predicted standardized changes in physical function measures after full covariate adjustment. Changes across sedentary variables explained 3-7% ($p<0.001$) of changes in walking speed and 2-4% ($p<0.001$) of changes in physical performance. Those who accumulated more sedentary time (1+, 10+, 30+, 60+ minute, and 50% bout length) or decreased sedentary breaks were more likely to experience declines in walking speed ($p<0.05$ for all). Furthermore, those with lower function at baseline appear to be more susceptible to declines in walking speed as sedentary time was increased ($p_{interaction}<0.05$). Similar results were observed with changes in SPPB (Figure 3-3).

Discussion

Mobility-limited older adults randomized to a two-year moderate intensity PA intervention not only increased their PA levels (89), but also reduced their time spent in accelerometry-derived sedentary time compared to those in a HE program. The PA intervention attenuated increases in time spent in short bouts (1+, 10+, & 30+ minutes); i.e., the largest reduction was observed in 10+ minute sedentary bouts, resulting in -1.4% less daily sedentary time. While these results support our original hypothesis that a PA program decreases sedentary time compared to the HE program, we found no intervention differences in prolonged sedentary metrics (60+ minute bouts, bout length representing 50% of daily sedentary accumulation, daily sedentary breaks). An additional finding was that changes in all sedentary bouts and bout lengths representing 50% of total daily sedentary time were negatively correlated with changes in physical function measures. This effect was stronger in participants with lower physical function at baseline. In support of these findings, decreases in sedentary breaks were associated with decreases in physical function. These results are unique to the sedentary behavior literature as they suggest that a traditional activity program can impact daily sedentary behavior metrics that appear to align with indicators of improved physical function.

At baseline, vulnerable older adults who were screened for low activity engaged in high rates of sedentary time across all bout lengths. In 2008, Matthews and colleagues used accelerometers to show that US adults 70-85 years of age spend about 9 hours, or 66% of daily waking time, in SB (74). Another study demonstrated that older women spent 65% of total sedentary time in 10+ minute bouts, 31% in 30+ minute bouts and 12% in 60+ minute bouts (105). These women also averaged 9 sedentary breaks/hour. In comparison, the current study showed that mobility limited older women and men spent 11 waking hours/day, or 77% of daily waking time, being sedentary at baseline. Almost 75% of the total daily sedentary time was accumulated through 10+ minute bouts, 46% through 30+ minute bouts, 22% through 60+ minute bouts and averaged 4 breaks/hour daily. Furthermore, half of their sedentary time was accumulated with 28+ min bout lengths. These rates were similar to a recent cross-sectional study examining accelerometry-determined sedentary time among US adult aged 60 years and older with mobility disability (defined as any difficulty walking ¼ mile or up 10 steps) (69). A large population-based study of black and white adults aged 45+ years spent 77%, 48%, and 26% in 10+, 30+, and 60+ minute sedentary bouts respectively (27). While these findings are similar to ours, caution must be taken when comparing results between these two studies, due to differences in accelerometer devices, activity count threshold criteria, screening criteria, and age of participants (90). Overall, it appears older adults at high risk for mobility disability are more sedentary than what others have reported in the literature.

Our results suggest long-term moderate intensity PA was most effective at decreasing short bouts of daily sedentary time, though the effects were relatively modest. The effects occurred within the first 6 months, and thereafter sedentary bout time steadily increased for both intervention groups. There were fewer intervention differences in long bouts of sedentary time. Longer bouts may be more resistant to change because they represent a relatively small amount of the total accumulated sedentary time. Further, results suggest that increases in prolonged sedentary time among mobility-limited older adults remained unchanged despite reporting high levels of moderate intensity PA (218 minutes/week) (89). Thus, older adults with mobility impairments who participate in a structured moderate intensity PA program appear to reallocate short, but not long, bouts of sedentary time (about 8-10 minutes/day) into active time.

We found a significant although relatively weak association between longitudinal changes in sedentary time and changes in physical function that was independent of intervention assignment. Our results suggest that increases in time spent across all sedentary patterns were correlated with decreases in lower-extremity physical performance and usual pace walking speed. Similar longitudinal analyses reported by Seguin and colleagues showed that greater amounts of self-reported sedentary time were linked with greater declines in self-reported physical function among postmenopausal women aged 50-79 years old (104). They showed that women reporting greater amounts of sedentary/sitting time had lower physical function at baseline and eventually declined more rapidly than those accumulating less sedentary/sitting time. These observations also support our findings that lower functioning participants at baseline were more susceptible to declines in physical function resulting from increases in sedentary time. Therefore, changes in sedentary time appear to play a role in changes in physical function among older adults with mobility limitations.

The strengths of this study include objective collection of daily PA via accelerometers in a randomized controlled trial design, multiple follow-up assessments over 24 months, a large sample of mobility-limited older adults, and high adherence to both interventions (median 24-month on-site attendance: PA[71%]; HE[82%]). Limitations include the inability to detect posture, sitting versus idle standing, sleep time, type of sedentary behaviors (e.g., educational reading versus television for entertainment), and possible wear/non-wear time misclassification. However, these effects are likely to be negligible because this population is less likely to stand for extended periods and Choi's classification algorithm reduces wear time misclassification among older adults (19).

In conclusion, these results suggest that mobility-limited older adults randomized to a 24-month moderate intensity PA program have a small but potentially beneficial reduction in short bouts of sedentary time. The effect did not transfer to prolonged sedentariness (60+ minute bout time, 50% bout length, sedentary breaks), although we found that 60+ minute bout time was relatively low in the sample to begin with. Further work is needed to explore whether moderate-intensity PA replaces sedentary time and how the type of PA influences sedentary time. Developing ways to increase PA among older adults remains a key public health goal and future interventions should consider integrating a sedentary behavior reduction component to maximize health benefits in this vulnerable population.

Table 3-1. Baseline participant characteristics by intervention assignment

	Physical activity (n = 669)	Health education (n = 672)
Age in years, mean(SD)	78.5 (5.3)	79.0 (5.3)
Female, n(%)	431 (64.4)	461 (68.6)
Non-Hispanic White, n(%)	497 (74.3)	520 (77.4)
College or higher education, n(%)	417 (62.3)	430 (64.0)
Body mass index (kg/m^2), mean(SD)	30.2 (5.8)	30.4 (6.3)
Smoked 100+ cigarettes ever, n(%)	339 (50.7)	297 (44.2)
Modified Mini-Mental State Examination score[a], mean(SD)	91.7 (5.4)	91.7 (5.3)
Sought medical advice for depression in past 5 years, n(%)	97 (14.5)	85 (12.7)
Comorbidities > 2, n(%)	172 (25.7)	177 (26.3)
Short Physical Performance Battery score[b], mean(SD)	7.5 (1.6)	7.3 (1.6)
Score < 8, n(%)	286 (42.8)	309 (46.0)
400 meter walk speed (m/sec), mean(SD)	0.8 (0.2)	0.8 (0.2)
Speed < 0.8 m/sec, n(%)	271 (40.5)	296 (44.1)
Wear days, mean(SD)	8.0 (3.3)	7.9 (3.1)
Wear minute/day, mean(SD)	839.1 (112.7)	835.0 (109.4)
Minutes/day ≥ 760 counts, mean(SD)	27.6 (22.8)	27.9 (25.9)
Daily sedentary time spent in 1+ minute bouts, mean(SD)	648.9 (120.3)	644.7 (112.4)
Daily sedentary time spent in 10+ minute bouts, mean(SD)	490.6 (136.4)	486.1 (127.0)
Daily sedentary time spent in 30+ minute bouts, mean(SD)	298.3 (136.5)	293.8 (128.8)
Daily sedentary time spent in 60+ minute bouts, mean(SD)	146.4 (105.8)	144.3 (100.1)
Average bout length spent in 50% of daily sedentary minutes (minute), mean(SD)	28.2 (13.4)	28.0 (13.2)
Daily number of sedentary breaks, mean(SD)	70.7 (17.6)	70.8 (18.1)

[a] score range: 0-100 where higher scores indicate better performance

[b] score range: 0-12 where higher scores indicate better performance; scoring < 8 indicates poor functioning

Table 3-2. Changes in sedentary behavior patterns and physical function by baseline SPPB[a] functional status

	Total (n=1,341)	Score <8 (n=595)	Score 8 or 9 (n=746)	p-value[b]
Sedentary variables[c,d]:		Mean (SD)		
1+ min sedentary bouts (minute/day)	0.76 (0.25)	0.77 (0.25)	0.74 (0.25)	0.08
10+ min sedentary bouts (minute/day)	1.28 (0.41)	1.31 (0.43)	1.26 (0.40)	0.03
30+ min sedentary bouts(minute/day)	1.60 (0.78)	1.66 (0.83)	1.55 (0.73)	0.007
60+ min sedentary bouts (minute/day)	1.39 (0.80)	1.51 (0.89)	1.30 (0.71)	<0.001
50% bout length (minute)	0.20 (0.01)	0.20 (0.02)	0.20 (0.01)	<0.001
Sedentary breaks (n)	-0.21 (0.10)	-0.22 (0.11)	-0.20 (0.10)	0.003
Physical function measures[c]:		Mean (SD)		
400-meter walk speed (m/s)	-0.002 (0.003)	-0.003 (0.003)	-0.002 (0.002)	<0.001
SPPB score	0.016 (0.041)	-0.011 (0.038)	0.038 (0.027)	<0.001

[a] Short Physical Performance Battery
[b] Significance at p<0.05
[c] Values represent beta coefficients (changes per month) derived from mixed effects linear regression over four time points
[d] Wear time was considered as a time-varying covariate

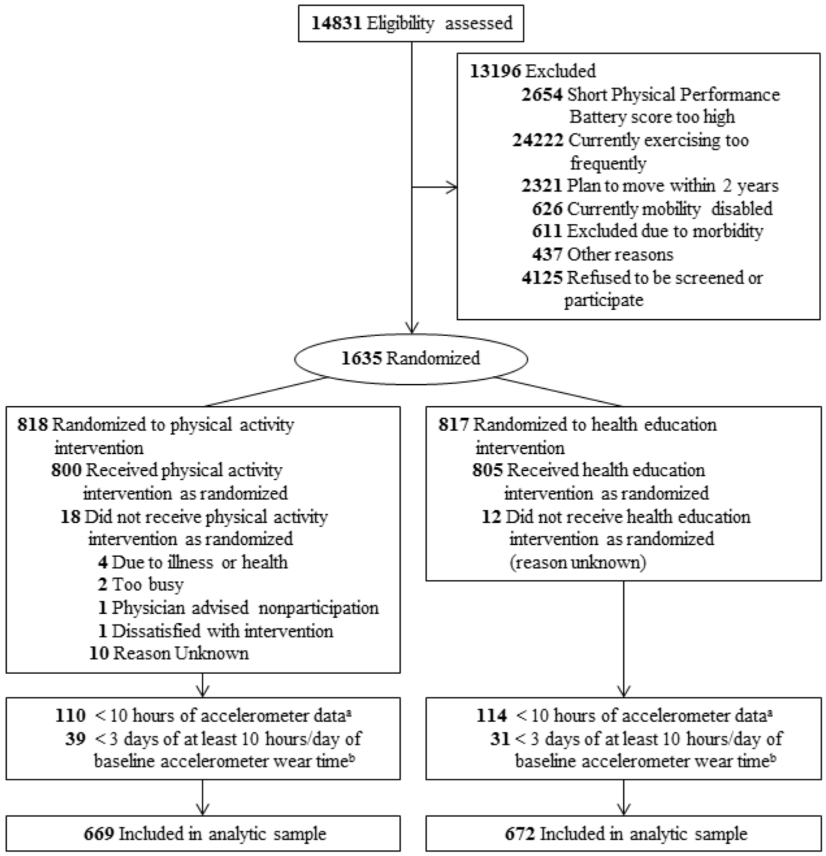

Figure 3-1. Flow of participants through the study. [a] Data pre-processed for at least 10 hours of accelerometer data which were screened for data key-in errors, accelerometer malfunctions, participant operation errors, visual identification of unexplained patterns or phenomenon, and duplicate files. [b] Data were screened for outliers and processed for valid wear/non-wear times based on a accelerometer wear time classification algorithm (18).

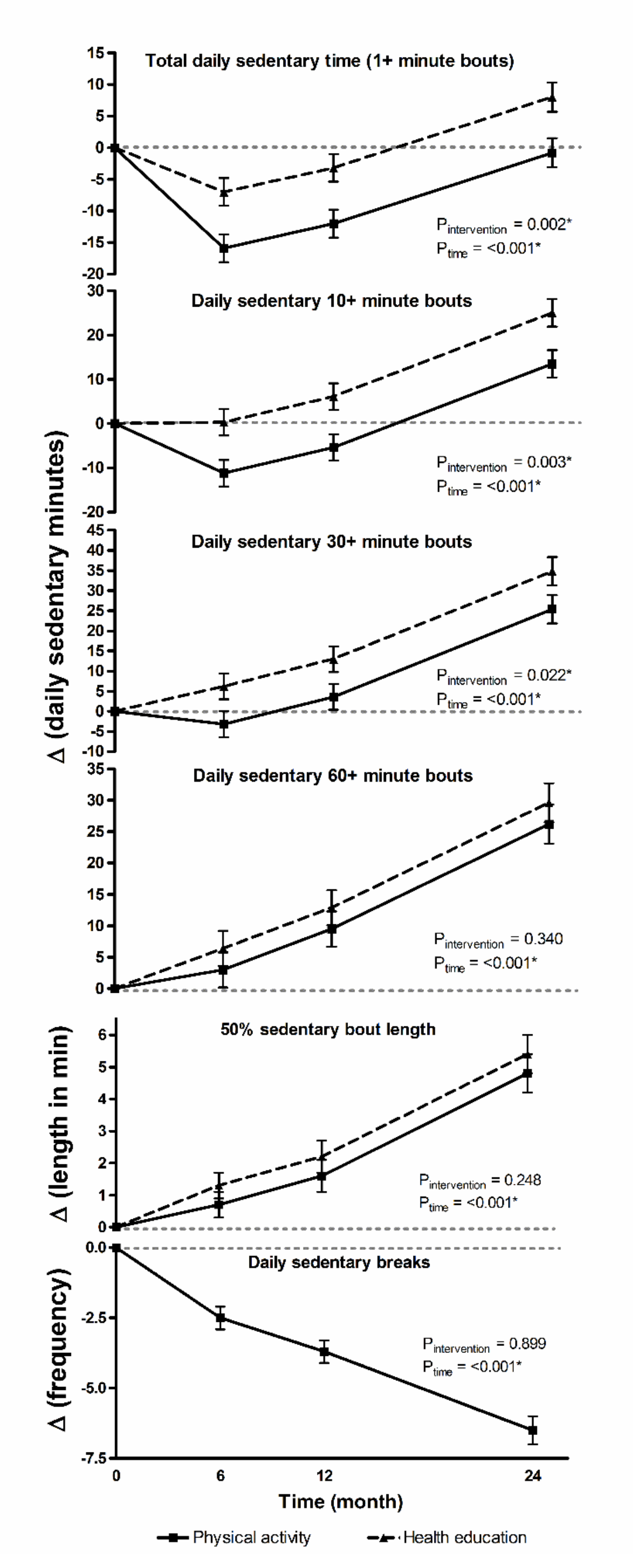

Figure 3-2. Intervention effect across sedentary measures. All models adjusted for baseline sedentary measure, age, gender, clinical site, and wear time. *p < 0.05; **p<0.01; ***p <0.001.

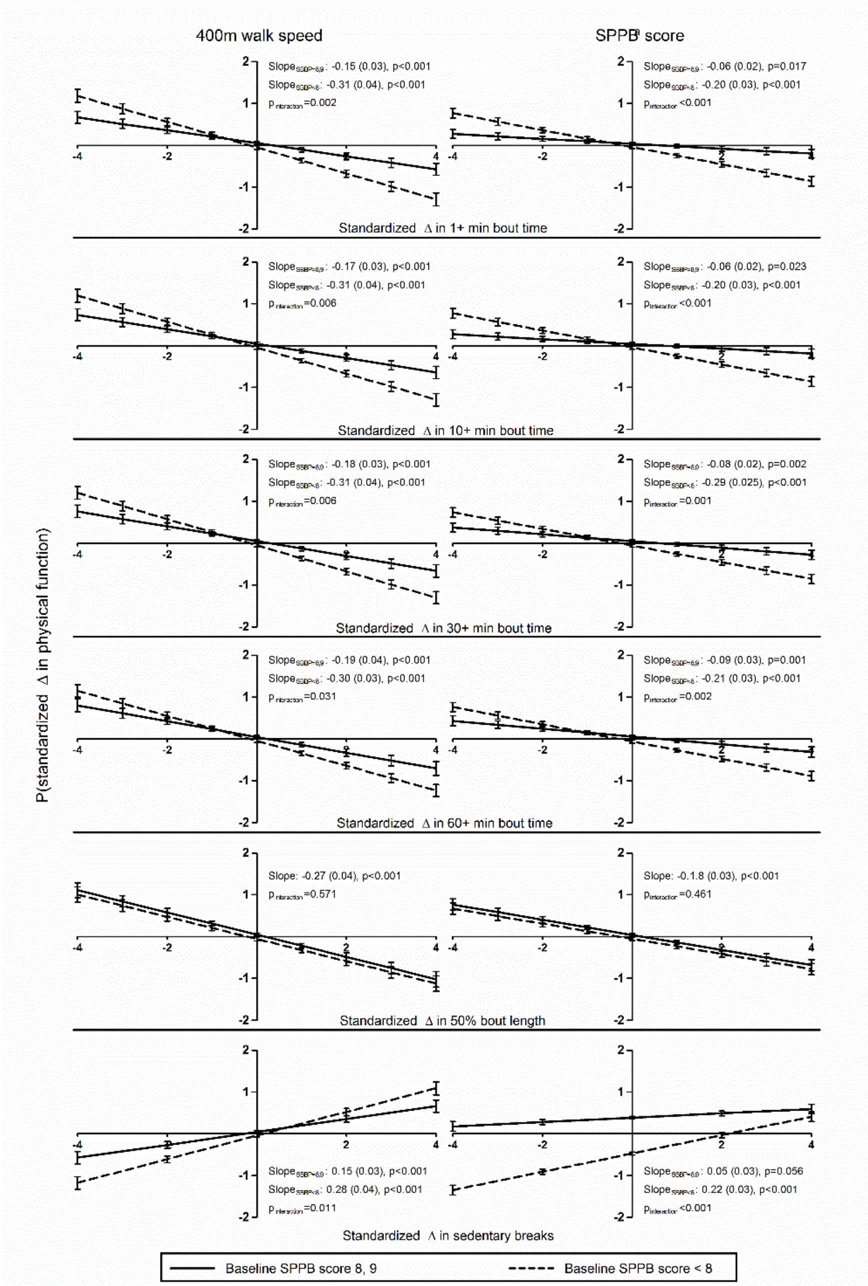

Figure 3-3. Association between standardized changes in sedentary measures and physical function. [a] Short Physical Performance Battery All models adjusted for baseline sedentary measure, baseline SPPB category (<8 vs. 8+ score as the reference), sedentary slope x SPPB category interaction term (included if significant at p<0.05), age, sex, intervention, clinical site, race/ethnicity, comorbidities > 2, education, modified mini-mental state examination score, self-reported depression, body mass index, smoked 100+ cigarettes during lifetime, daily activity (accelerometer minutes registering 760+ counts/minute).

CHAPTER 4
EFFECTS OF A LONG-TERM MODERATE INTENSITY EXERCISE PROGRAM ON PHYSICAL ACTIVITY COMPOSITION IN MOBILITY IMPAIRED OLDER ADULTS

Background

Adults aged 70+ years of age represent the most physically inactive age segment of the US population (114) and they are linked to a high risk for physical disability and loss of independence (59). Large-scale physical activity interventions, such as the Lifestyle Interventions and Independence for Elders (LIFE) study (32), were developed to evaluate combating the negative effects of physical inactivity on mobility and independence. This was accomplished by facilitating older adults' engagement in the Federally-recommended amount of 150 minutes per week of structured moderate to vigorous intensity physical activity (MVPA; otherwise considered as exercise) (15). Specifically, the Federal guidelines recommend engaging in at least 30 minutes of continuous, structured physical activity for most, if not all, days. For those who have difficulty reaching 30-minute physical activity bouts, the guidelines recommend performing multiple 10+ minute bouts of activity. Despite these recommendations, there is little work to verify that physical activity interventions influence engagement in these types of activity bouts—particularly in vulnerable older adults who may have impediments to performing longer duration exercise.

Previous research has identified that exercise interventions impact not only MVPA, but also lighter intensity activities in older adults (44). Several studies in younger populations demonstrated that long-term exercise increased total daily physical activity suggesting that lighter intensity, non-exercise activities are preserved (20, 79, 95, 99). Meijer and colleagues demonstrated that adults 28-41 years of age who trained 5 months for a 1/2 marathon competition increased total daily physical activity (79).

Therefore, the exercise training program did not affect non-exercise activity, resulting in the observed increase of total amount of physical activity accumulated throughout the day. However, evidence in older adults suggests that exercise training has no impact on total daily physical activity, which may indicate that lighter intensity activities reduces with long-term exercise (44, 77, 78, 82). Older adults who undertook vigorous endurance training demonstrated no changes in total daily energy expenditure (44). This suggests a compensation effect whereby lighter intensity activities reduced to accommodate increased engagement in higher intensity activities. However, the compensation effect remains largely unconfirmed in long-term, large-scale randomized trials and particularly among vulnerable older adults with mobility limitations. Furthermore, there has been little work to examine this compensation effect of physical activity according to frequency, duration, and intensity (120).

Measuring physical activity is challenging because it is difficult to precisely describe intensity patterns in free-living conditions. There are a multitude of measurement tools to assess physical activity including questionnaires, doubly-labeled water, and electronic sensors, all of which capture physical activity in different ways. However, some of these methods are limited in their ability to simultaneously capture all the complex components of daily physical activity such as frequency, duration, and intensity. Questionnaires are cost effective measurement tools that excel at qualitatively capturing types and contexts of activities and are easily deployed in large-scale research. However, validity (when compared to more objective methods) of these instruments is considered poor (57). Doubly labeled water is considered the gold standard method to indirectly measure free-living total caloric energy expenditure (101), but this method is costly for large scale research studies and unable to capture the type or intensity of specific activities performed during the monitored time period (121). Fortunately, innovations in engineering in the past couple decades have provided an objective method to assess movements continuously in free-living environments (38). Body worn accelerometers offer a non-invasive, reasonably cost-effective, and continuous measure of movement patterns throughout a waking day while also being well suited for evaluating behavioral studies such as physical activity interventions. Accelerometers have greatly expanded the measurement of physical activity by objectively capturing the composition of activity by intensity, duration, and frequency patterns (91).

The primary aim of this analysis was to examine how a long term, moderate intensity physical activity intervention modified time spent at different intensities of physical activity as measured using an accelerometer. We hypothesized that the physical activity intervention would increase total daily time spent in levels within moderate intensity physical activity (low and high+) by replacing time spent in light intensity physical activity (low and high) when compared to a general health education program. Second, we aimed to determine whether the physical activity intervention modified patterns of engagement within different intensities. We hypothesized that the physical activity intervention would increase total daily time spent in 10+ minute bouts at all physical activity intensities when compared to a health education group. These hypotheses were tested in the LIFE study, which provides a unique opportunity to analyze accelerometer data collected at multiple time points over 2 years. The LIFE study enrolled a large sample of mobility-limited older adult population who were randomized into either a moderate intensity physical activity (PA) or a health education (HE) intervention (32).

Methods

Trial Design and Participant Population

Details outlining the study design and methods (32) and primary results (89) can be found elsewhere. In short, the LIFE study was a Phase 3, multicenter, investigator-blinded, randomized clinical trial testing the capability of a physical activity intervention to reduce the risk of major mobility disability among mobility limited older adults. A total of 1,635 men and women were recruited. Eligible participants were 70-89 years of age and sedentary (defined as self-reporting < 20 minute/week getting regular physical activity within the last month) and were tested for functional limitations operationally defined as scoring < 10 on the Short Physical Performance Battery (SPPB), where 12 was the highest physical performance achievable. Moreover, eligibility required the ability to walk 400 meters within 15 minutes without sitting, leaning, or receiving any assistance. Participants were excluded for the following reasons: not willing to be randomized, self-reported inability to walk across a room, diagnosis of psychotic-related conditions, low mental health, progressive neurological conditions, alcohol abuse, speech or hearing problems, severe arthritis, plans to relocate in the near future, living in a nursing home, LIFE-pilot intervention participation, active treatment for cancer, regular use of corticosteroids or supplemental oxygen needed for lung disease, cardiovascular disease, dialysis required for renal disease, safety concerns such as chest pains or shortness of breath during the 400 meter walk, life expectancy was less than 12 months due to severe illness, and any clinical judgements concerning safety or study non-compliance. The LIFE study was registered with www.clinicaltrials.gov before trial enrollment (NCT01072500). The study protocol was approved by the institutional review boards at all participating sites and is available on request at https://www.thelifestudy.org/public/index.cfm. All participants provided written informed consents.

Interventions

Participants were randomized either to the PA intervention or the HE program at baseline using a block algorithm (random block lengths) stratified by field center (8 centers throughout the United States) and sex. After randomization, participants received an individual face-to-face introductory session with a health educator who described the intervention, expectations, and fielded any questions. Both programs promoted behavioral change based on social cognitive theory principles and strategies were developed around the Transtheoretical Model (94). The PA intervention comprised of an individually tailored plan to increase physical activity levels with a goal of achieving 150 minutes/week of moderate intensity physical activity through the promotion of multiple 10+ minute bouts. This involved aerobic exercise through a walking regimen that also included lower extremity strength exercises, flexibility, and balance training. The PA intervention design consisted of 2 center-based sessions and 3-4 home exercise sessions that accompanied the in-person sessions. The Borg's scale for rating perceived exertion was utilized to determine whether participants attained moderate intensity physical activity (8). Participants were asked to reach an intensity of 13 (perceiving activity as "somewhat hard") within a 6-20 range. Strength exercises consisted of 2 sets of 10 repetitions, where participants were asked to reach a 15 to 16 (perceiving activity as "hard") on the Borg's scale. The HE group participated in conversational workshops focused on older adult health and well-being, while intentionally avoiding topics related to physical activity. A few examples of the topics were the US healthcare system, how to travel safely, access to preventive services, and reliable health information sources. Additionally, participants in the HE group were led through a 5- to 10-minute light intensity upper extremity stretch and relaxation component during each session. Participants in the HE group were expected to meet weekly during the first 26 weeks of the intervention and at least once monthly thereafter.

Accelerometer Measurements

Tri-axial accelerometers (Actigraph™ GT3X) were administered to all participants at baseline and then at 6, 12, and 24-month follow-up visits. These devices detect accelerations within a magnitude range of 0.05 to 2.5 units of gravity, digitize the analog signals at a rate of 30 Hertz (Hz), and pre-process data through a band filter to eliminate non-human motion. Samples were summed over a 1-second interval, otherwise termed as epoch, and converted to activity counts. An activity count is a unit-less quantity of overall movement expressed as a rate (e.g., counts/minute). Participants were instructed to wear the accelerometers on their right hip at all times for 7 consecutive days, except during sleep and water-related activities (e.g., swimming or showering). While tri-axial accelerometer data were collected on the hip, only vertical axis data (most sensitive to ambulatory movements) were used in the current analysis (37, 73).

Physical Activity Characterization

The accelerometer provides no information about whether a participant was wearing the device. Therefore, accelerometer data were first processed to classify valid wear time using Choi's non-wear algorithm (18). This algorithm improves on previous methods at detecting low intensity activity, particularly in those who are expected to accumulate prolonged bouts of inactivity (114). In short, data were binned into 1-minute epochs and scanned for at least 90 minutes of consecutive zero counts. Any other non-zero count registered by the accelerometer was considered wear time. Non-zero counts were only allowed for up to two-minute intervals but within at least 30-minute upstream and downstream zero count windows. Outliers were identified as minutes where activity counts exceeded 10,000 counts/min, 3,500 counts over median of the 2nd highest activity counts/minute across all days, or 1,000 counts over the 2nd highest activity counts/minute of the same day. Minutes classified as outliers were re-labeled as non-wear time and not included in the analysis. Further, the data were visually inspected for unexplainable phenomenon (e.g., maintaining the same activity level for extended periods of time at extremely high levels of activity), which were removed ad-hoc. In total, 34 of the 3,102 days (0.01%) from 18 participants were removed: 1 day from baseline, 7 at 6 months, 5 at 12 months, and 21 from 24 months. Only participants who provided valid accelerometry (10+ hours/day of accelerometer data for at least 3 days at all time points; n=1,341) were included in the analytic sample.

Physical activity patterns were characterized by intensity and bout lengths. Each valid wear minute was labeled as activity (of any intensity) if counts summed to 100+ activity counts over 1 minute. Accelerometer variables and accelerometer cut-points were calculated according to Table 4-1. The sum of all activity-labeled minutes was calculated as total activity (TPA) and categorized into low light physical activity (LLPA), high light physical activity (HLPA), low moderate physical activity (LMPA) and high moderate and greater physical activity (HMPA). These cut-points were chosen because they have been specifically evaluated among older adults (23, 37, 114). The percent contribution of intensity-specific activity to TPA was derived as follows: (minutes in intensity-specific activity) / (TPA) * 100. For example, the percent contribution of HLPA to TPA was calculated as: total HLPA / (TPA) * 100.

Bouts of activity time were calculated as consecutive minutes of at least 1+, 2+, 5+, and 10+ minutes where the accelerometer registered within cut-points specified in Table 4-1. Time spent in 1+ minutes of activity bouts represent the total volume of intensity-specific activity, where 2+, 5+, and 10+ minute bout lengths represent consecutively smaller segments of the total activity volume. We chose to examine overlapping categories of activity (e.g., 2+ minute bouts contain 5+ and 10+ minute bouts) because physical activity recommendations are typically disseminated with no upper limit. However, mutually exclusive categories can be calculated; for example, if 5+ minute bouts were subtracted from 2+ minute bouts, the subsequent segment would represent 2.0-4.9 minute bouts.

Other Measurements

Participants were assessed at the clinical site at baseline and every 6 months thereafter by study staff masked to intervention group assignment. Information on age, sex, along with other sociodemographic factors, medical history, hospitalizations, medications, quality of well-being, and functional limitation were collected via self-report at baseline.

Statistical Analysis

Activity bout time distributions were assessed for normality within each intensity range prior to performing analyses. Mixed effects (random and fixed) linear regression models were constructed for each bout length and intensity level. Visit (time) was treated as a repeated factor, and the baseline activity-specific metric, age, visit, and wear time were included as fixed effects. Factors used to stratify randomization (sex and clinical site) were also included in both models as fixed effects. Also, the interaction between intervention and visit was tested for each model and included if found to be significant. Alpha level for all analyses was set to 0.05. Accelerometer data were processed using R (www.r-project.org) (18, 115) and statistical analyses were performed in STATA v13 (STATA Corp.).

Results

Sample Characteristics

Baseline participant characteristics according to intervention group are described in Table 4-2. Randomized groups were similar across demographics, behavioral factors, and medical history. Participants were 78.7±5.3 (SD) years and predominately females (66.5%) and non-Hispanic white (75.8%). Mean wear time was 13.9±1.8 wear hours/day for 7.9±3.2 days. Those with invalid accelerometer data (n=294) were similar in age (79.6±5.0 years old) and sex (70.1% women) compared to the sample with valid accelerometer data.

Activity Intensity and Bout Lengths at Baseline

Baseline daily activity patterns expressed in minutes per day (minutes/day) by specific bout length are presented in Table 4-3. On average, participants spent 189.7±69.9 minutes/day in TPA, which made up 22.8±8.2% of total daily wear time. 86.7±8.0% of daily TPA was spent in LLPA, 6.1±2.9% in HLPA, 5.9±4.3% in LMPA, and 1.3±2.8% in HMPA. Within LLPA, 72.6±7.2%, 23.7±8.6%, and 4.7±4.0% was spent in 2+, 5+, and 10+ minute bouts, respectively. 21.6±11.0%, 1.2±4.1%, and 1.0±1.2% HPLA time was spent in 2+, 5+, and 10+ minute bouts, respectively. Of total LMPA time, 35.9±19.0%, 8.1±13.9%, and 2.5±9.0% was spent in 2+, 5+, and 10+ minute bouts, respectively. For HMPA, 29.7±32.0%, 8.8±20.3%, and 3.3±12.8% was spent in 2+, 5+, and 10+ minute bouts, respectively. No differences were noted between randomized groups.

Most participants engaged in at least 1 minute of 1+, 2+, 5+ and 10+ minute bouts in LLPA (>85%) during baseline accelerometry collection, which was also true for 1+ and 2+ minute bouts at HLPA and LMPA. However, in general, participants engaged in less activity with longer bout lengths and relatively higher intensity. Less than 15% of participants engaged in 10+ minute bouts at HLPA, LMPA and HMPA.

Intervention Effects on Intensities in Total Activity Time

Figure 4-1 illustrates changes in intensity patterns within TPA per month. The PA group decreased daily time spent in LLPA when compared to the HE group, with the highest impact observed at 6 months (-3.3±0.4%) but reduced by 24 months (-1.8±0.4 %; $p_{interaction} < 0.001$). In comparison, the HE group increased time spent in LLPA by 0.8±0.3% (p=0.008) over 24 months. In contrast to LLPA, the PA group increased time spent in HLPA, LMPA, and HMPA when compared to the HE group. Intervention differences for HLPA and LMPA were 0.3±0.1% (p<0.001) and 1.3±0.2% (p<0.001), respectively. For HMPA, intervention differences were highest at 6 months (1.4±0.2%) but reduced by 24 months (0.4±0.2 %; $p_{interaction} < 0.001$).

Intervention Effects on Time Spent at Intensities and Bout Lengths

Figure 4-2 depicts changes in time spent at intensity by bout lengths per month. Both groups decreased TPA time in 1+ bouts (-0.9±0.1 minutes/day), 2+ bouts (-0.6±0.1 minutes/day), 5+ bouts (-0.2±0.0 minutes/day), and 10+ minute bouts (-0.1±0.0 minutes/day). However, the PA intervention attenuated TPA decreases across 1+, 2+, and 5+ minute bouts while increasing time in 10+ minute bouts when compared to the HE program (1+ bouts: 6.4±2.1 minutes/day; 2+ bouts: 5.4±1.6 minutes/day; 5+ bouts:

3.6±0.9 minutes/day; 10+ bouts: 3.3±0.4 minutes/day). After separating TPA by intensity, no intervention differences were detected for all bout lengths in LLPA. For HLPA, the PA intervention attenuated decreases in 1+ bouts (0.8±0.3 minutes/day) but not 2+ minute bouts ($p=0.46$) while increased time in longer bouts (5+ minute bouts: 0.2±0.04 minutes/day; 10+ minute bouts: 0.1±0.02 minutes/day). Intervention differences found in 1+, 5+, and 10+ minute HLPA bouts were maintained for 24 months. The PA intervention increased time in all LMPA bout lengths. Increases in 1+ bouts (2.7±0.4 minutes/day), 2+ bouts (2.4±0.3 minutes/day), and 10+ minute bouts (1.1±0.1 minutes/day) were maintained for 24 months whereas 5+ minute bout increases were highest at 6 months (2.0±0.2 minutes/day), maintained at 12 months (1.7±0.3 minutes/day, $p_{6vs12\ diff}=0.12$), and reduced by 24 months (12 vs 24 months: 0.36±0.3 minutes/day, $p<0.001$). For HMPA, the impact of the intervention was highest at 6 months where the PA intervention increased time in all bouts (1+ bouts: 2.8±0.4 minutes/day; 2+ bouts: 2.5±0.3 minutes/day; 5+ bouts: 2.1±0.3 minutes/day; 10+ minute bouts: 1.7±0.2 minutes/day). All increases in HMPA bouts reduced by 24 months ($p_{interaction}<0.001$ for all).

Discussion

The results provide an important understanding of the activity pattern changes that occur in response to a long-duration physical activity program in vulnerable older adults. First, the PA intervention changed total daily activity by increasing HLPA, LMPA, and HMPA. These increases appeared to be at the expense of a decrease in LLPA. Despite increased HLPA, LMPA, and HMPA, the PA group continued to experience an overall decline in total daily activity, albeit less than the HE group. Additionally, the PA intervention increased engagement in long duration bouts of 10+ minutes of activity within HLPA, LMPA, and HMPA (but not LLPA) when compared to the HE program. This finding was also supported by an increased time in short bouts of HLPA (1+ and 5+), LMPA (1+, 2+, and 5+), and HMPA (1+, 2+, and 5+). It is important to note that group differences at lighter intensity bouts were not a sole result of increased physical activity in the PA group, but an attenuated decline when compared to the HE group.

To our knowledge, this is the first study to characterize activity composition among older adults aged 70-89 years old who were considered to be inactive (<20 minute/week of structured physical activity) and had low physical function according to a standardized assessment battery (47). At baseline, LIFE participants accrued lower amounts of physical activity and performed less activity in longer bouts when compared to other studies on older adults. In 2008, Troiano and colleges reported from NHANES (National Health and Nutrition Examination Survey) data that older adults (70+ years) spent ~7 minutes/day of HMPA whereas our sample of mobility-limited older adults spent 3 minutes/day (114). In a subsequent study by Evenson et al. using updated data, older adults accumulated ~52 minutes/day in HLPA, which is considerably higher than the 13 min/day in LIFE study participants (31). Additionally, in these same reports, older adults spent 3-7 minutes/day in 10+ minute bouts of HMPA, whereas the LIFE sample spent 0.5 minutes/day (31, 114). More recently, Buman and colleges reported average time spent in LLPA + HLPA (257 minutes/day), LMPA (19 minutes/day), and HMPA (10 minutes/day) in 70+ year olds were substantially higher than participants in the LIFE study (12). These comparisons suggest that LIFE study participants were indeed less active across activity intensities and accumulated their activity in shorter bouts compared to the general population and previous reports.

The PA intervention was most effective at increasing long term, moderate intensity physical activity but at the cost of decreasing time spent at light intensities, confirming our first hypothesis. These results support previous findings that older populations do not simply add exercise into their daily lifestyle but compensate by reducing low intensity activities to accommodate higher intensity activity. This finding of a compensation effect is supported by previous studies implementing exercise training programs in older adults (44, 77, 78). In 1992, investigators observed no change in total physical activity, despite increases in vigorous intensity exercise measured through energy expenditure (44). Authors concluded that though older adults did not change total energy expenditure through a possible compensatory reduction in non-exercise activity, the high intensity training may have fatigued the participants afterwards. In 1999, a study using accelerometers assessed how a 3-month moderate intensity training program impacted daily physical activity in older adults aged 55-68 years old (78). Participants trained twice a week and accelerometry data were collected on training and non-training days. Results showed that training days showed a significant decrease of non-training physical activity when compared to physical activity accumulated on non-training days even with a lower intensity exercise program. Our results add to these findings by confirming the replacement effect occurring among older adults at high risk of mobility disability. Unique to the literature is that we determined compositional changes in intensity levels of daily physical activity using accelerometers. At baseline, LIFE participants spent approximately 20% of total waking time in some form of physical activity. Of this 20%, LLPA was most predominant, reaching >80% of TPA. Over 24 months, the PA group experienced decreases in LLPA when compared to HE; the most observed at 6 months (-3%). At 6 months, the PA group concurrently increased time in HLPA, LMPA, and HMPA by 3% percent. Though intervention differences significantly reduced over time, the observed replacement effect was preserved over 24 months.

It appears that modifying the intensity composition of total daily activity can impact the maintenance of mobility and independence among vulnerable, older adults. In 2015, the LIFE study demonstrated that the PA intervention conferred mobility and health benefits to mobility-limited older adults (89). This appears to occur by replacing LLPA with higher activity intensities. Other studies have shown improvements in physical function and health markers, but not increases in total physical activity, associated with exercise training (44, 77, 78, 89). In contrast, the HE group increased time in LLPA by replacing time in HLPA, LMPA, and HMPA and supports previous evidence of declines in physical activity after reaching the age of 60 years old (119). Daily intensity shifts within TPA were also experienced by the HE group but with higher activity intensities being replaced by LLPA. These results indicate that changes in the composition of physical activity intensities may be important for understanding transitions in disability and/or disease progression states (28), particularly among older adults with mobility impairments.

Participants in the PA intervention averaged 32-44 more minutes registering at or above 760 counts/minute per week than the HE group, which was similar to accelerometer data reported by Pahor and colleagues (89). By using Copeland's cut-points (23), we found these intervention differences consisted of 6 minutes/week spent in HLPA, 19 minutes/week in LMPA and 20 minutes/week in HMPA at 6 months, 14 minutes/week at 12 months and 7 minutes/week at 24 months. For LLPA, no group differences were observed. When combining all intensity levels, PA intervention accrued an average of 45 more minutes/week of TPA than the HE program. However, both groups experienced overall decreases in time spent in TPA over 24 months (-6 minutes/week of TPA per month), which was primarily driven by decreases in LLPA (-4 minutes/week of LLPA per month). Additionally, we were able to examine intervention effects on volumes and bout patterns according to intensity level. In general, the PA intervention influenced bout patterns similar to their respective volumetric times. Intervention effects observed within HLPA and LMPA occurred similarly across longer bout times. However, intervention effects reduced over time for LMPA 5+ minute bouts and all HMPA bouts. The results support our second hypothesis that the PA intervention increased time spent in 10+ minute bouts at physical activity at all intensities when compared to the HE group. However, bouts of LLPA were unchanged. Additionally, the PA intervention attenuated but did not eliminate total daily physical activity declines despite increasing 10+ minute bouts of physical activity at higher intensity levels.

We were able to objectively evaluate a long-term physical activity intervention designed to increase amount of time and Federally-recommended physical activity guidelines. This capability was not restricted to the laboratory but expanded into free-living settings, revealing a novel and potentially useful way to assess unsupervised adherence. This is particularly important among older adults who have low adherence to unsupervised exercise programs while at home (16, 97). To do this, we combined commonly used accelerometer cut-points calibrated for adult populations (20+ years of age) to examine how the PA intervention influenced time spent at different activity intensities and bout lengths (23, 37, 114). This approach to examine intervention effects on daily activity accumulation patterns is unique to the accelerometer literature, particularly in vulnerable older adults at high risk of mobility disability.

Strengths of this study include objective collection of daily PA via accelerometers, repeated measures of accelerometry over 24 months in a randomized controlled trial design among a large sample of older adults at high risk of mobility disability. The study had a few limitations. Specifically, lack of knowledge regarding posture— ability to detect standing versus sitting, sleep, and type of activity (e.g. structured exercise versus gardening) may misclassified activity as inactivity, potentially underestimating intervention effects. However, this population is less likely to stand for extended periods of time and the wear time classification algorithms reduces wear time misclassification among older adults (18).

In conclusion, a structured, moderate intensity physical activity increased time in physical activity bouts in higher intensities at the expense of very light intensity physical activity. These results highlight that the PA intervention increased physical activity by shifting the composition of activity toward higher intensity activity in longer duration bouts. However, the PA intervention did not eliminate overall declines in total daily activity patterns experienced by mobility impaired older adults. Further work is needed to understand the declines in total activity because it appears that increasing longer bouts of high intensity physical activity does not completely eliminate declines in total activity experienced by older adults highly vulnerable to mobility disability.

Table 4-1. Descriptions of accelerometer-derived metrics of physical activity composition

Intensity	Bouts
Light physical activity (LLPA): • 100-759 counts/minute	1. Time spent in 1+ min bouts (minutes/day; total activity time)
High light physical activity (HLPA): • 760-1,040 counts/minute	2. Time spent in 2+ min bouts (minutes/day)
Low moderate physical activity (LMPA): • 1,041-2019 counts/minute	3. Time spent in 5+ min bouts (minutes/day)
High moderate physical activity (HMPA): • 2,020+ counts/minute	4. Time spent in 10+ min bouts (minutes/day)
Total physical activity (TPA): • 100+ counts/minute	

Table 4-2. Baseline participant characteristics by intervention group

	Physical activity (n = 669)	Health education (n = 672)
Age in years, mean(SD)	78.5 (5.3)	78.9 (5.2)
Female, n(%)	431 (64.4)	461 (68.6)
Non-Hispanic White, n(%)	497 (74.3)	520 (77.4)
College or higher education, n(%)	417 (62.3)	430 (64.0)
Body mass index (kg/m^2), mean(SD)	30.2 (5.8)	30.5 (6.3)
Smoked 100+ cigarettes ever, n(%)	339 (50.7)	297 (44.2)
Modified Mini-Mental State Examination score[a], mean(SD)	91.7 (5.4)	91.7 (5.3)
Sought medical advice for depression in past 5 years, n(%)	97 (14.5)	85 (12.7)
Comorbidities > 2, n(%)	172 (25.7)	177 (26.3)
Short Physical Performance Battery score < 8[b], n(%)	286 (42.8)	309 (46.0)
400 meter walk < 0.8 m/sec, n(%)	271 (40.5)	296 (44.1)
Wear days, mean(SD)	8.0 (3.3)	7.9 (3.1)
Wear minute/day, mean(SD)	839.1 (112.7)	835.0 (109.4)
Minutes/day ≥ 760 counts, mean(SD)	27.6 (22.8)	27.1 (25.9)

[a] score range: 0-100 where higher scores indicate better performance
[b] score range: 0-12 where higher scores indicate better performance; scoring < 8 indicates poor functioning

Table 4-3. Baseline daily activity level and bouts by intervention group

	Physical activity (n=669)		Health education (n=672)	
	mean (SD), minutes/day	n (%)[a]	mean (SD), minutes/day	n (%)[a]
	Low light minutes (100-759 counts/minute)			
1+ minute bouts	161.9 (54.4)	669 (100)	162.1 (54.5)	672 (100)
2+ minute bouts	120.1 (47.5)	669 (100)	120.3 (47.2)	672 (100)
5+ minute bouts	41.7 (25.8)	668 (99.9)	41.3 (24.7)	672 (100)
10+ minute bouts	8.5 (8.8)	597 (89.2)	8.5 (8.6)	595 (88.5)
	High light minutes (760-1,040 counts/minute)			
1+ minute bouts	12.6 (9.3)	669 (100)	12.6 (9.3)	672 (100)
2+ minute bouts	3.1 (3.1)	634 (94.8)	3.1 (3.1)	625 (93.0)
5+ minute bouts	0.1 (0.5)	94 (14.1)	0.2 (0.6)	83 (12.4)
10+ minute bouts	0.01 (0.2)	3 (0.5)	0.02 (0.2)	7 (1.0)
	Low moderate minutes (1,041-2,019 counts/minute)			
1+ minute bouts	12.3 (11.5)	668 (99.9)	12.6 (13.5)	671 (99.9)
2+ minute bouts	5.4 (6.8)	622 (93.0)	5.9 (8.9)	621 (92.4)
5+ minute bouts	1.2 (2.9)	306 (45.7)	1.7 (4.6)	302 (44.9)
10+ minute bouts	0.4 (1.6)	72 (10.8)	0.7 (2.9)	82 (12.2)
	High moderate minutes (2,020+ counts/minute)			
1+ minute bouts	2.7 (5.7)	577 (86.3)	2.7 (6.4)	577 (85.9)
2+ minute bouts	1.6 (4.6)	331 (49.5)	1.7 (5.0)	320 (47.6)
5+ minute bouts	0.8 (3.6)	127 (19.0)	0.9 (3.7)	112 (16.7)
10+ minute bouts	0.4 (2.6)	45 (6.7)	0.5 (2.6)	54 (8.0)

[a] Frequency of those who spent any time in that activity level (min/day > 0)

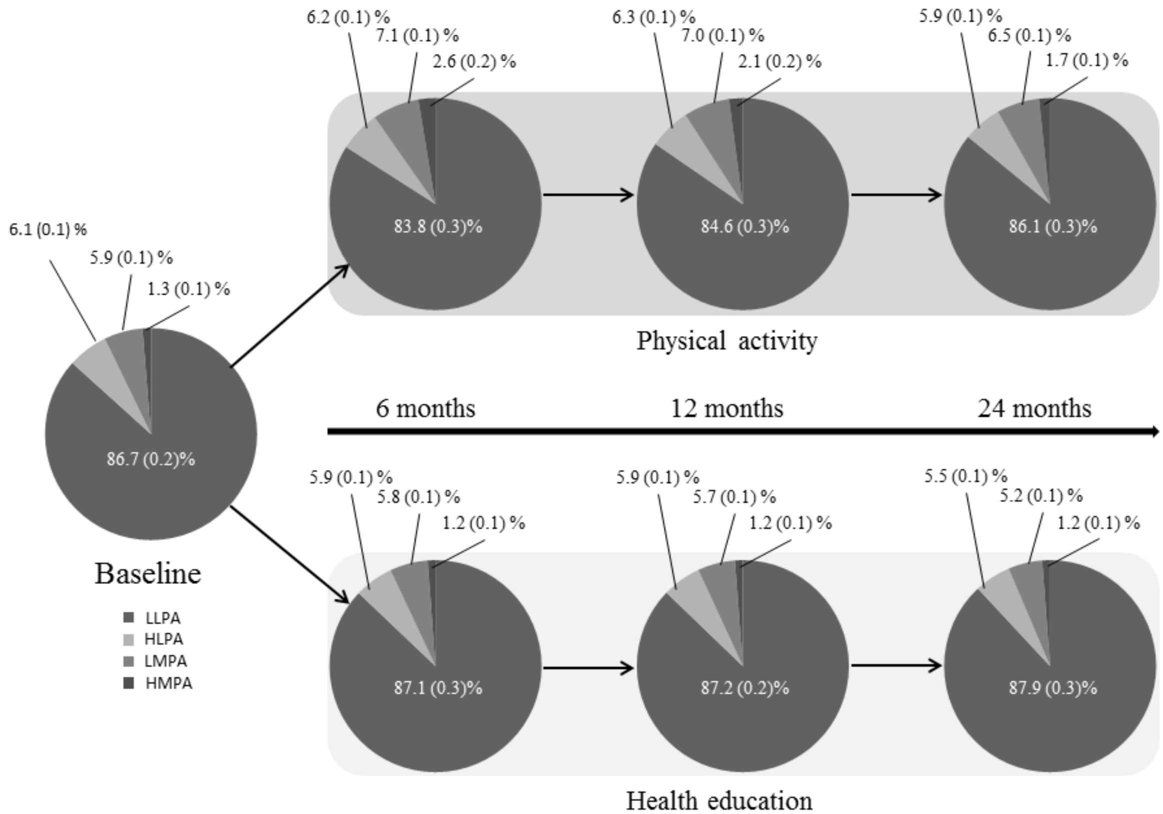

Figure 4-1. Compositional changes of total daily physical activity by intensity and intervention status. All models adjusted for baseline activity variable, age, sex, clinical site, and wear time. Note: LLPA – low light physical activity; HPLA – high light physical activity; LMPA – low moderate physical activity; HMPA high moderate and greater physical activity. *p < 0.05; **p<0.01; ***p <0.001

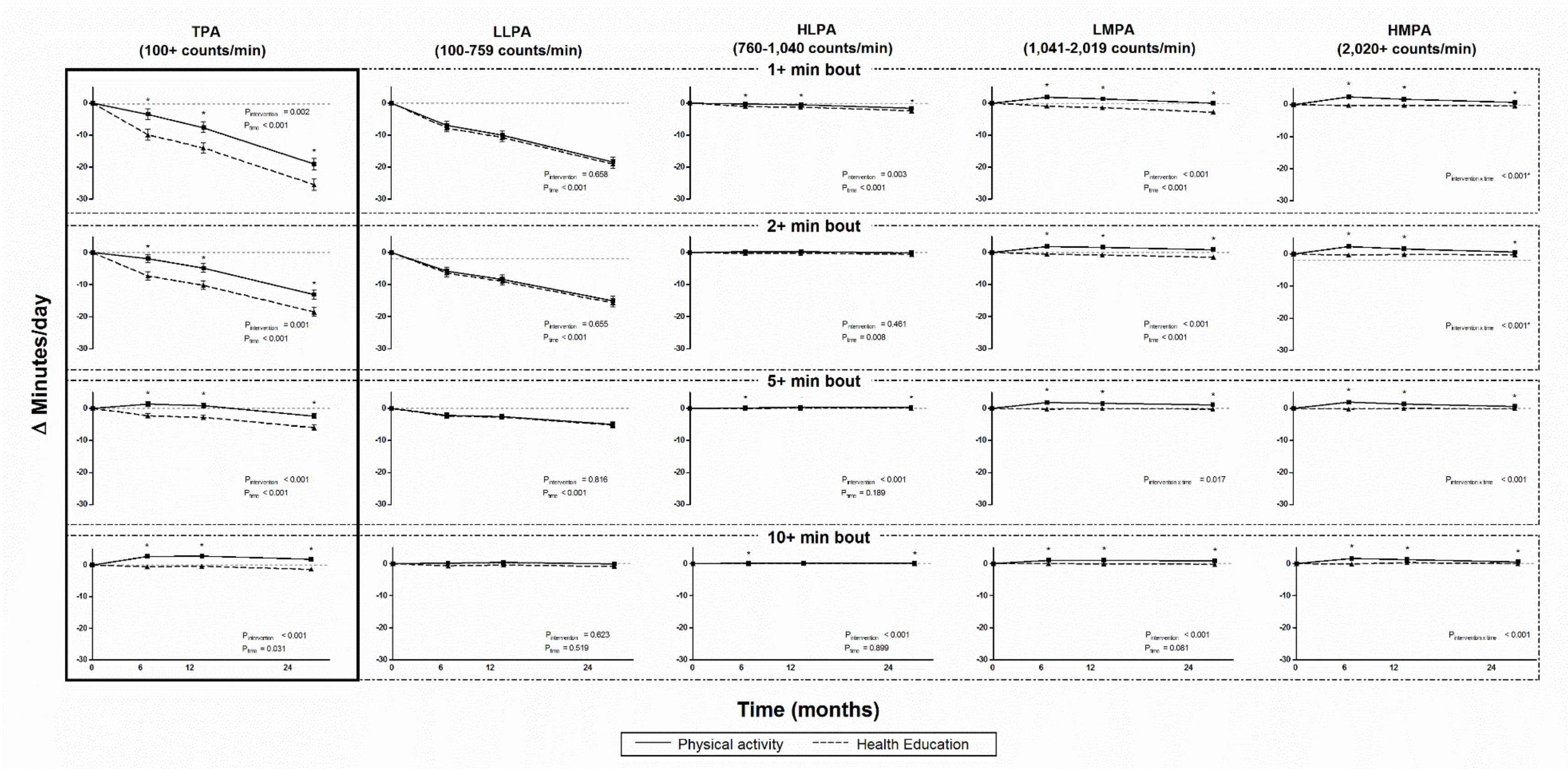

Figure 4-2. Intervention effects on activity intensity levels by bout pattern. All models adjusted for baseline activity variable, age, sex, clinical site, and wear time. Note: TPA – total physical activity; LLPA – low light physical activity; HPLA – high light physical activity; LMPA – low moderate physical activity; HMPA high moderate and greater physical activity. *Physical activity vs health education. $p < 0.05$; **$p<0.01$; ***$p <0.001$

CHAPTER 5
INVESTIGATING THE INTERVENING EFFECT OF HOSPITALIZATIONS ON PHYSICAL ACTIVITY PATTERNS MEASURED BY ACCELEROMETRY

Background

A hospitalization event is an independent predictor of poorer musculoskeletal, autonomic, circulatory, urinary, sensory, and metabolic health systems, all of which lead to subsequent functional decline and changes in daily physical activity patterns (25, 45). Despite the fact that hospitalizations are intended for restoration from adverse health conditions, the degree of imposed immobility and disparate complications to the cause of hospitalization only partially explain accelerated declines in physical function following a hospitalization in older adults (25, 43). This has become a critical public health issue among older adults (≥ 70 years of age), a rapidly growing segment of the US population at high risk for physical disability (17, 70). Furthermore, older adults at risk for disability who experience a hospitalization from intervening illness or injury are more likely to develop outright disability when compared to their less vulnerable counterparts (41).

Induced physical inactivity, which accompanies and follows a hospitalization, is associated with mortality, morbidity, and disability (81, 88). However, the relationship between hospitalizations and subsequent changes in both physical inactivity and activity is not well known, particularly in free-living settings. This is important because older adults represent the most sedentary segment in the US (74) and excess sedentary volumes have been linked to adverse health outcomes (53, 62, 75), independent of moderate-to-vigorous physical activity. Regular physical activity is known to delay mortality, morbidity, and disability (83) but is also known to decline immediately after hospitalization (96). Hospitalizations could partially describe the large activity declines that occur during the aging process, placing those hospitalized on a new trajectory of increased physical inactivity and declining physical activity. Additionally, the manner in which inactivity and activity are accrued after hospitalizations remains unclear but has drawn focus. For example, prolonged sedentary bouts is linked to poorer cardiometabolic profiles when compared to taking frequent breaks in sedentary behavior (51, 52). Federal guidelines of regular physical activity promote physical activity participation in continuous bouts of 10 minutes or more for older adults but the temporal effect of hospitalizations on daily activity patterns remains unclear. There remains a public health need to examine the role that hospitalizations have in daily activity changes characterized across volume, duration and intensity, particularly among older adults vulnerable to disability and hospitalizations.

In the Lifestyle Interventions and Independence for Elders (LIFE) study, a long-term structured moderate-intensity physical activity (PA) program reduced the risk of major mobility disability in 1,635 sedentary men and women aged 70+ years of age with mobility limitations, when compared to a health education (HE) program (89). Though hospitalizations within the PA group were slightly higher compared to HE, the PA intervention did not statistically increase the risk of hospitalizations by comparison (71). Despite having slightly higher rates of hospitalizations, the PA group accumulated 32-44 more minutes per week of accelerometry-derived physical activity (minutes registering at 760+ counts) (89). More interventions are being developed to promote recovery of hospitalizations through exercise training, but they are limited to short study periods (26). There remains a knowledge gap of the degree to which a long-term structured physical activity intervention improves regular physical activity levels and decreases sedentary times, particularly among vulnerable older adults who experience at least one hospitalization.

The LIFE study provides a unique opportunity to examine the complex relationship between intervening hospitalizations, structured physical activity intervention, and daily accrual of sedentary and activity times through objective measures using a hip-worn accelerometer collected periodically over 2 years. As such, we are able to characterize changes in patterns of inactivity and activity by volume, duration, and intensity. Additionally, we can determine hospitalizations not only by occurrence but also by cumulative length of stay in a hospital setting (hospital duration). Therefore, the primary aim was to examine the impact of an intervening hospitalization on daily accelerometry-derived levels of physical inactivity and activity. We hypothesized that an intervening hospitalization is associated with increases in sedentary time and decreases in physical activity when compared to those without a hospitalization. Additionally, we hypothesized that long hospital durations had greater associations than short durations. The secondary aim was to assess whether the intervening hospitalization's impact on daily patterns of inactivity and activity is different between intervention groups. We hypothesized that those randomized to PA have attenuated increases in sedentary time while experiencing attenuated decreases in physical activity patterns when compared to HE. Among those with long hospital durations, the beneficial PA effects are greater than those with short hospital durations.

Methods

Trial Design and Participant Population

Study design and methods details (32) and primary results (89) are outlined elsewhere. Briefly, the LIFE study was a Phase 3, multicenter, investigator-blinded, randomized clinical trial examining the ability of a structured, moderate-intensity physical activity intervention to reduce the risk of major mobility disability among mobility-limited older adults. A total of 1,635 men and women were enrolled. Those eligible were 70-89 years of age and sedentary (defined as self-reporting < 20 minutes/week getting regular physical activity within the last month and < 125 minutes/week of moderate-intensity physical activity). Eligible participants were screened for functional limitation, defined as scoring < 10 (of 12) on the Short Physical Performance Battery (SPPB), where 12 was the highest physical performance achievable. Further, eligibility required participants to possess the ability to walk 400 meters within 15 minutes without sitting, leaning, or receiving any assistance. Exclusion criteria were as follows: unwilling to be randomized, self-reported not able to walk across a room, diagnosis of psychotic-related conditions, low mental health, progressive neurological conductions, alcohol abuse, hearing or speed problems, severe arthritis, plans to relocate in the near future, living in a nursing home, LIFE-pilot intervention participation, active treatment for cancer, regular use of corticosteroids or supplemental oxygen needed for lung disease, cardiovascular disease, dialysis required for renal disease, safety concerns such as chest pains or shortness of breath during the 400 meter walk, life expectancy < 12 months due to severe illness, and any clinical judgments concerning safety or study non-compliance. Study protocols were approved by the institutional review boards at all participating sites and is available on request at www.thelifestudy.org/public/index.cfm. All participants gave written informed consents.

Interventions

Baseline randomization of participants was performed using a block algorithm (random block lengths) stratified by field center (8 centers throughout the United States) and sex to either the PA intervention or the HE program. An individual face-to-face introductory session with a health educator was held for each participant where the intervention and expectations were described and questions were answered. Behavioral change was promoted through both programs using social cognitive theory principles and strategies developed around the Transtheoretical Model (94). The PA intervention consisted of an individually tailored plan to increase physical activity with a goal of achieving 150 minutes/week of moderate-intensity physical activity through the promotion of multiple 10+ minute bouts. This plan was comprised primarily of aerobic exercise through a walking regimen but also included lower extremity strength exercises, flexibility, and balance training. The PA intervention design comprised of 2 center-based sessions accompanied by 3-4 home exercise sessions. Rate of perceived exertion using the Borg's scale was used to ensure compliance to a program of moderate intensity physical activity (8). Participants were asked to reach an intensity of 13 (perceiving activity levels as "somewhat hard") within a 6-20 range. Strength exercises comprised of 2 sets of 10 repetitions, where participants were asked to reach a 15-16 (perceiving activity as "hard") on the Borg's scale.

Participants were placed on medical leave if the participant missed, or voluntarily or temporarily withdrew from physical activity treatment for 4+ consecutive sessions due to self-reported hospitalization, injury, or other health reasons. Additionally, a participant may be classified as on medical leave if their primary care physician orders withdrawal from physical activity. Participants on medical leave were periodically contacted for a status update while also provided with support and development of plans to restart the intervention when appropriate. Suspended physical activity was restarted when the participant was able to leave home and independently walk a minimum of 4 meters. The participant had to have any prescribed therapy completed prior to restarting the PA program. All participants underwent individualized re-evaluations to modify the physical activity prescription to cope with any conditions caused or attained during the hospitalization.

The HE intervention consisted of conversational workshops focused on older adult health and well-begin (e.g., US healthcare system, how to travel safely, reliable health information sources, etc.), while intentionally avoiding topics related to physical activity. Additionally, participants in the HE group were led through a 5-10 minute light intensity upper extremity strength and relaxation component during each session. Participants in the HE intervention were expected to meet weekly during the first 26 weeks of the intervention and at least once monthly thereafter.

Accelerometer Measurements

A hip worn accelerometer (Actigraph™ GT3X) was used to collect daily activity patterns at baseline and then at 6-, 12-, and 24-month follow-up visits. In the LIFE study, accelerometers were utilized detect accelerations within a magnitude range of 0.05-2.5 units of gravity. These signals were digitized from analog signals at a rate of 30 Hertz (Hz) and pre-processed through a band-pass filter to eliminate non-human motion noise. Samples were summed into 1-second epochs (time intervals) and converted to activity counts. An activity count is defined as a unit-less quantity of overall movement expressed as a rate (e.g., counts/minute) that is correlated with the intensity (i.e., speed) and number of movements over a given time period. Participants were instructed to wear the accelerometer on their right hip at all waking times for 7 consecutive days, except during sleep and water-related activities (e.g., swimming or showering). While accelerometer data were collected on three axes, only vertical axis data (most sensitive to ambulatory movements) were used in this paper (37).

Accelerometer Variables

The monitor continuously logs movement and non-movement, but does not provide a specific distinction between wear and non-wear times. Therefore, accelerometer data was first processed for valid wear time periods using a non-wear algorithm developed by Choi and colleagues (18). This algorithm was chosen because it improves on the National Health and Nutrition Examination Survey (NHANES) algorithm to determine low activity levels from sedentary behavior, particularly in those who are expected to have prolonged bouts of sedentary time (19). Briefly, 1-second epoch data were binned into 1-minute epochs and scanned for consecutive zero counts lasting at least 90 minutes. Exceptions for non-zero counts within non-wear periods were only allowed for up to 2-minute intervals but within at least a 30-minute upstream or downstream zero count window. Any other non-zero count registered by the accelerometer were considered wear time. Outliers were identified as minutes where activity counts exceeded 10,000 counts/min, 3,500 counts over median of the 2nd highest activity counts/minute across all days, or 1,000 counts over the 2nd highest activity counts/minute of the same day. Minutes classified as outliers were re-labeled as non-wear time and not included in the analysis. Further, the data were visually inspected for unexplainable phenomenon (e.g., maintaining the same activity level for extended periods of time at extremely high levels of activity), which were removed ad-hoc. In total, 34 of the 3,102 days (0.01%) from 18 participants were removed: 1 day from baseline, 7 at 6 months, 5 at 12 months, and 21 from 24 months. Only participants who collected valid accelerometry— defined as 10+ hours/day of accelerometer data for at least 3 days at all time points (n=1,341)— were included in the analytic sample.

Accelerometer variables and accelerometer cut-points were calculated according to Table 5-1. Each valid wear minute was labeled as sedentary if counts summed to <100 over 1 minute (74, 75, 114). Each valid wear minute was labeled as activity (of any intensity) if counts summed to 100+ activity counts over 1 minute. Total physical activity (TPA) was defined as the sum of all activity-labeled minutes and categorized into low light physical activity (LLPA), high light physical activity (HLPA), low moderate physical activity (LMPA) and high moderate and greater physical activity (HMPA). These cut-points were chosen because they have traditionally been used in the literature or that they have been specifically determined for older adults.

Bouts of activity were studied to understand the how sedentary and activity times were patterned throughout the day. Sedentary bouts were calculated as consecutive sedentary minutes of at least 1+, 10+, 30+, or 60+ minutes described in Table 5-1. Activity bouts were calculated as consecutive minutes of at least 1+, 2+, 5+, and 10+ minutes where the accelerometer registered within cut-points specified in Table 5-1. Time spent in 1+ minutes of activity bouts represent the total volume of intensity-specific activity, where longer bout lengths represent consecutively smaller segments of the total activity volume. We chose to examine overlapping categories of activity (e.g., 2+ minute bouts contain 5+ and 10+ minute bouts) because physical activity recommendations typically have no upper limit. However, mutually exclusive categories can be derived; for example, if 10+ minute bouts were subtracted from 5+ minute bouts, the subsequent segment would represent a 5.0-9.9 minute bout length.

Hospitalization Variable

The hospitalization event, date and reason were collected continuously throughout the study. Masked assessors collected this information during scheduled clinic visits using an outcome events questionnaire. Medical record technicians and adjudicators verified the reason and date of hospitalization by reviewing medical records. For this analysis, only hospitalizations reported to masked staff at the scheduled follow-up visits were considered as an event. Unmasked hospitalizations were not considered to reduce ascertainment bias of the PA participants who were permitted to freely report events to unmasked interventionists during intervention sessions (<10% out of total hospitalization reported were unmasked).

The variable for hospitalization combined the event and the length of stay. To do this, hospital length of stay (LOS; in days) was summed between each time interval of baseline to 6 months, 6 to 12 months, and 12 to 24 months. Those without a hospital stay received a zero. The LOS of variable was categorized into short and long durations by splitting the variables at the median of 4 days spent in a hospital setting among those hospitalized. The variable was expressed as no hospitalizations (0 hospital days), short cumulative hospital duration (1-3 hospital days), and long cumulative hospital duration (4+ hospital days) within each time interval per participant.

To verify hospitalizations that occurred before accelerometry collection, overlap between hospitalizations and accelerometer collection periods were examined. Of 3,176 follow-up observations, 10 (0.003%) were found to overlap. Observations with overlap were not considered in this analysis.

Covariates

At baseline, information on age, sex, race/ethnicity, education, marital status, income, and smoking status were collected via self-reported along with medical/hospitalization history, physical examinations, cognitive testing (Modified Mini-Mental State Examination; 3MSE), body weight, and height. Participants' physical function was assessed at the clinical site at baseline and every 6 months thereafter by study staff masked to intervention group assignment. Walking speed was assessed during a 400-meter walk where participants were asked to complete 10 laps on 20-meter course at their usual pace. Participants were allowed to stop and take a break for up to 1 minute without sitting during the assessment. If a participant stopped before the 10 laps were completed, the distance traveled was measured. Walking speed was calculated as distance/time (meters/second). The SPPB was used to assess physical performance via balance, usual gait speed, and chair stand tests. Each component was scored from 0 to 4, with higher scores indicating better performance. Summing the components yielded a total score from 0 to 12, where 12 was the highest score of physical performance.

Statistical Analysis

Baseline differences between hospitalization duration categories were tested by either t-tests (means) or chi-square tests (frequency) within each intervention group. To assess changes in accelerometer outcomes, each metric was subtracted by baseline values for each participant. Distributions of accelerometer change metrics were assessed for normality within each accelerometer cut-point range and time interval prior to conducting analyses. Mixed effects (random and fixed) linear regression models were constructed for each accelerometer metric (cut-point- and bout length-specific) where visit (time interval) within a participant was treated as a repeated factor. The unadjusted regression model for each outcome was as follows:

$$Y_{ij} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i})t_{ij} + \beta_2 \text{Hospitalization}_{1-3} + \beta_3 \text{Hospitalization}_{4+} + \beta_4 \text{Intervention} + \beta_5 (\text{Intervention} \times \text{Hospitalization}_{1-3}) + \beta_6 (\text{Intervention} \times \text{Hospitalization}_{4+}) + e_{ij} \quad (5\text{-}1)$$

where Y_{ij} is the outcome (accelerometer metric) for the *i*th participant at the *j*th visit, $\text{Hospitalization}_{1-3}$ and $\text{Hospitalization}_{4+}$ are dummy variables for the categories of the hospitalization variable (e.g., $\text{Hospitalization}_{1-3}$ = 1 if the participants spends 1-3 days in a hospital setting, $\text{Hospitalization}_{1-3}$= 0 otherwise), and t_{ij} is the time interval (in y) from baseline for the *i*th subject at the *j*th visit. The random intercept is b_{0i} (i.e., the deviation of the *i*th participant's intercept from the mean population intercept, β_0) and the random slope is b_{1i} (i.e., the deviation of the ith participant's slope from the mean population slope, β_1). For this analysis, the parameters of interest were β_2 and β_3, which tested whether the change in accelerometer metric outcomes were different for participants who spent 1-3 or 4+ days in a hospital setting, respectively, when compared to those who spent no time in a hospital setting (β_1, reference). Also, β_5 and β_6 tested whether post-hospital changes (either 1-3 days or 4+ days) in accelerometer metric outcomes were different by intervention group when compared to the reference of participants who did not spent time in the hospital in each intervention group. For both aims, the interaction of time with other parameters of interest was tested but found not to be significant for any of the models (p<0.05 for all). After running unadjusted models, final models excluded non-significant interaction terms and were fully adjusted by demographic, behavioral, and medical history covariates. A priori contrast statements were used to estimate the difference between short and long hospital durations on each accelerometer outcome. There was a potential for hospitalizations, which occurred closer to accelerometer collection, to have more impact on change in accelerometer patterns. Therefore, regression models were used to test whether days from the most recent hospitalization discharge date to subsequent accelerometer collection was correlated with changes in any accelerometer parameter. Two-tailed alternative hypotheses and type 1 error rate of 0.05 were used for all analyses. Accelerometer data were processed using R (www.r-project.org) (18, 115) and statistical analyses were performed in STATA v13 (STATA Corp.).

Results

Sample Characteristics

Baseline participant characteristics according hospitalization status within intervention assignment are described in Table 5-2. A total of 1,341 participants collected at least 10 hours of valid accelerometer data for at least 3 days at baseline. Of those, 669 were randomized to the PA group and 672 were randomized to the HE group. Those without valid accelerometry data (n = 294) were similar in regard to age (79.6±5.0 years old; mean ± SD) and sex (70.1% women) as compared to the sample who had valid accelerometry data but differed by cognition (-1.7 3MSE score), walking speed (-0.03 m/s), physical performance (-0.3 SPPB score) and LOS among those hospitalized (+1.8 hospital days).

Randomized groups were similar across demographics, behavioral factors, and medical history where participants were 78.7±5.3 (SD) years, predominately females (66.5%), non-Hispanic white (75.8%) and collected an average of 13.9±1.8 wear hours/day for 7.9±3.2 days. Furthermore, participants in the PA group who experienced at least one hospitalization (n=187) were similar to those not hospitalized (n=482) across demographics, behavioral factors, cognition, depression, medical conditions, physical function, and accelerometer wear metrics but not for self-reported hospitalizations in the past 6 months from baseline (11% vs. 5%, respectively, p=0.01). Those hospitalized during the HE program (n=171) were older, had lower body mass index, and had higher rates of 2+ comorbidities compared to those who did not experience a hospitalization (n=501; p<0.05 for all). Additionally, those in HE group who had experienced a hospitalization were more likely to have had a previous hospitalization in the past 6 months at baseline, lower physical function, lower walk speed, and, on average, spent less time in activity minutes registering greater than or equal to 760 counts (p<0.05 for all).

Figure D1 describes the number of hospitalized participants, the number of hospitalizations, and the average length of stay per hospitalizations by intervention group within each time interval. The first time interval (baseline to 6 months), 10% of the participants experienced at least one hospitalization in the PA group. There was a rate of 1.4 hospitalizations per hospitalized PA participants, who averaged 5 LOS per hospitalization. Similarly, 8% of the HE participants experienced at least one hospitalization, had a rate of 1.2 hospitalizations among those hospitalized, and averaged 4 LOS per hospitalization. The second and third time intervals were similar in all hospital characteristics by intervention. Overall, the cumulative characteristics are presented in Table 5-3. Of the total sample, 358 (27%) participants of the analytic sample experienced at least one hospitalization and were similar between randomized groups. Among those hospitalized, 18%, 5.4%, and 3.3% experienced 1, 2, and 3 or more hospitalizations, respectively. Participants who experienced at least one hospitalization spent an average of 5.4±6.2 days in the hospital across all assessment intervals. Participants who experienced a short (1-3 days) and long (4+ days) hospitalization duration averaged 2.0±0.8 days and 7.9±6.8 days across all assessment intervals, respectively.

Baseline Accelerometer Metrics

Between randomized groups, accelerometer metrics were similar for sedentary bouts and categories of TPA bouts (LLPA, HLPA, LMPA, and HMPA) showed in Table 5-4. Participants averaged 646.8±116.4 min/day total daily sedentary time (1+ min bouts; 77.2% of total daily wear time) at baseline. On average, 488.3±131.8, 296.0±132.7, and 145.4±102.9 min/day were spent in 10+ min, 30+ min, and 60+ min sedentary bouts, respectfully. On average, participants spent 189.7±69.9 min/day in daily TPA (22.8±8.2% of total daily wear time), where 86.7±8.0% of daily TPA was spent in LLPA, 6.1±2.9% in HLPA, 5.9±4.3% in LMPA, and 1.3±2.8% in HMPA.

Among the PA group, baseline accelerometer metrics were different across hospitalization categories where there were higher sedentary and lower activity patterns with longer hospitalization lengths except for total sedentary time and 10+ LLPA minute bouts (Table 5-4). Additionally, there were no differences found for 5-10+ HLPA minute bouts, 5+ LMPA minute bouts, and 5-10+ HMPA bouts; all of which participants spent ≤ 2 minutes daily (Table 5-4). There were differences in baseline accelerometer metrics across hospitalization categories in the HE group where there were higher sedentary and lower activity patterns with longer hospitalization lengths, except for 5-10+ HLPA & LMPA minute bouts, and all HMPA minute bouts (Table 5-4).

Hospitalization Effect on Accelerometer Metrics

The correlation between days from most recent hospitalization discharge to subsequent accelerometer collection was not correlated with the change in any accelerometer parameter (Figure E-1). The effect of hospitalization on changes in daily accelerometer metrics over 24 months are presented in Table 5-5. For the PA group, a positive association with both short and long hospital durations was found for 1+ sedentary minute bout change when compared to no hospitalizations ($p<0.05$). A positive association was found in only long durations and changes in bout patterns of 10+ and 30+ sedentary minutes ($p<0.05$ for all). There was a significant trend of increasing sedentary time across higher hospital durations for all bout lengths among the PA group (except 60+ sedentary minute bouts; trend $p>0.05$). For the HE group, positive associations with long durations were found for all sedentary bout lengths when compared to no hospitalizations ($p<0.01$ for all). For HE, there was a significant trend of increasing sedentary time with longer hospital durations (trend $p<0.05$). When the groups were combined, a positive association with both short and long durations was found for daily total sedentary time (+7.5±3.1 daily minutes, $p<0.05$ for short duration; +16.2±12.2, $p<0.001$ for long duration). Only long durations were associated with 10+, 30+, and 60+ sedentary minute bout changes ($p<0.001$ for all). A significant trend of increasing sedentary time as hospital duration became longer was found for all sedentary bout lengths among the pooled groups ($p<0.05$ for all).

Both short and long hospital durations were associated with 1+ and 5+ TPA minute bout declines when compared to no hospitalizations in the PA group ($p<0.05$ for both) where only long durations were associated with decreased time spent in 2+ TPA minute bouts ($p<0.001$). A significant trend of declining TPA time was observed as hospital durations became longer for 1+, 2+, and 5+ minute TPA bouts ($p<0.05$ for all). For the HE group, only long durations were associated with 1+ and 2+ minute TPA bout declines when then those without a hospitalization ($p<0.05$ for both). There was a trend of TPA decline with longer hospital durations for these bout lengths ($p<0.05$ for both). The pooled group who experienced short and long durations had lower time spent in 1+, 2+, and 5+ TPA minute bouts than those without a hospitalization ($p<0.05$ for all) and experienced a significant trend of decreasing TPA time in these bouts as hospital durations became longer (trend $p<0.05$ for all).

Different intensity levels were examined by hospitalization status and interventions. Those with a short duration hospitalization demonstrated a decline in 1+, 2+, and 5+ LLPA minute bouts ($p<0.05$ for all) and 1+ and 2+ HLPA minutes bouts ($p<0.05$ for both) for the PA group. This decline was more severe in those with a long duration hospitalization for 1-2+ LLPA & HLPA minute bout ($p<0.05$ for all) and 1+, 2+, and 5+ LMPA minute-bout ($p<0.05$ for all). For the HE group, only the 1+ and 2+ LLPA minute-bouts were negatively impacted by a long-duration hospitalization ($p<0.01$ for both). In the pooled group, short durations were associated with declines in 1-5+ LLPA minute bouts ($p<0.05$ for all), 1-2+ HLPA minute bouts ($p<0.05$), and 1-5+ LMPA minute bouts. For long durations, negative associations were found for changes in 1-5+ LLPA minute bouts ($p<0.05$), 1-2+ HLPA minute bouts ($p<0.001$), and 1-5+ LMPA minute bouts ($p<0.05$). All bout lengths significantly impacted by a hospitalization in PA, HE, and the pooled group showed a significant trend towards greater declines in activity as hospital durations became longer (trend $p<0.05$ for all). For the HE group, 2+ HLPA bouts and 1+ minute LMPA bouts showed a significant trend towards greater activity decline with longer hospital durations (trend $p<0.05$) though no significant hospitalization impact was observed for either short or long hospital durations.

Hospitalization's Impact on Accelerometer Metrics between Interventions

Table 5-5 presents the p-value testing whether the impact of hospitalization on daily inactivity/activity patterns was different between intervention groups in the far right column. Across all accelerometer metrics, those hospitalized for either short or long durations did not differ from those who did not experience hospitalization ($p_{PA\ vs\ HE} >0.05$), independent of intervention effects on accelerometer outcomes. Additionally, there was no detectable interaction between hospitalization and intervention by time for all metrics ($p_{interaction}>0.05$ for all). Figure E-2 describes the intervention effect over 2 years, independent of hospitalization status. The PA group experienced a decrease in sedentary time for 1+ minute bouts (-8 minutes, p=0.005) and 10+ minute bouts (-10 minutes, p=0.009) compared to the HE group. Also, the PA group experienced increased daily time in TPA across all bouts (3-6 minutes, p<0.01 for all). Figure E-3 further describes intervention effects on TPA by intensity category. The both hospitalized and non-hospitalized PA participants experienced increases in 10+ minute LLPA bouts (1 minute, p=0.03), all bouts lengths in HLPA (0.1-0.8 minutes, p<0.01), LMPA (1.1-2.8 minutes, p<0.001), and HMPA (1.2-1.9 minutes, p<0.001) when compared to HE. As bout lengths became longer, increases appear to be lower.

Discussion

This is the first study to examine the intervening effect of hospitalizations on objectively measured sedentary and physical activity patterns in mobility-limited older adults. Among LIFE participants, we found that an intervening hospitalization is associated with subsequent increases in short bouts of sedentary time (<10 minutes) and declines in short bouts of physical activity ranging from LLPA (<10 minutes) to HLPA (<5 minutes). Further, those who accumulated more than 3 hospital days experienced magnified increases in all sedentary bouts while experiencing greater declines in total daily physical activity primarily due to declines in LLPA bouts (<10 minutes), HLPA bouts (<5 minutes), and LMPA bouts (<10 minutes). We found that those who experience 4+ cumulative hospital days, but not 1-3 days, had increases in sedentary bouts > 10 minutes, and declines in shorter LMPA bouts (<10 minutes). While these results support our primary hypothesis, we found that long bouts of physical activity (10+ minutes) were largely unaffected by hospitalizations across all activity levels. Also, an overall intervening hospitalization did not impact bouts lasting 5 minutes or longer in HLPA. Additionally, hospitalization did not impact HMPA whatsoever regardless of the length of cumulative hospital days. Finally, a structured moderate-intensity physical activity intervention did not attenuate the negative, intervening effect of hospitalization on daily activity patterns compared to health education, which was contrary to our second hypothesis. Additionally, there was no evidence to show that the PA exacerbated the activity patterns after hospitalization. Yet, intervention effects on accelerometer metrics, such as decreases in sedentary patterns or increases in activity patterns, were still experienced by the PA group, regardless of hospitalization status. These findings increase understanding of the degree to which hospitalizations influence patterns of free-living sedentary and physical activity and its relation to a long-term, structured physical activity intervention in mobility-limited older adults.

There is sparse literature characterizing sedentary patterns in free-living conditions among older adults who have experienced a hospitalization. Previous observational studies show that >80% of a hospitalized stay is spent in sedentary time determined by activity monitors (11, 76). In recent observational studies, hospitalized older adults who survived a stroke had higher total sedentary time after hospitalization when compared to matched counterparts with no existing medical problems, which remained even 6 months after the hospitalization (80, 112). Our results are similar by showing that older adults at risk for mobility disability increased their total daily sedentary time after a hospitalization. The current work extends this knowledge by showing the effect is primarily seen in short rather than long bouts of sedentary time. Notably, all patterns of sedentary time, particularly long bouts, were increased when an intervening hospitalization extended to 4+ days spent in a hospital setting. Thus, an overall intervening hospitalization (short or long durations) appears to increase short sedentary bouts where only longer hospital durations extends this effect to longer sedentary bouts. Increases in sedentary time did not diminish in hospitalized LIFE participants, suggesting a new permanent and new trajectory towards overwhelming inactivity beyond normal aging effects. The coupling effect of hospitalization and aging on sedentary behavior may help describe the accelerated trajectory towards functional loss and transitions into disability states (42, 43).

Existing literature demonstrates that physical activity patterns are reduced among hospitalized older adults when compared to disability-free and non-hospitalized counterparts (66, 92, 98). A recent observational study showed that older adults who were hospitalized for a stroke had reduced objectively measured walking patterns (short and long distances) 40 months later when compared to older adults who did not experience stroke and lived without disability (98). Our results similarly show no indication that pre-hospital patterns of activity were regained, suggesting that hospitalizations are associated with permanent and deleterious effects on daily activity patterns. Additionally, we showed that hospitalizations in LIFE participants largely affected short (<5 minutes), rather than long bouts of activity which lasted 5 minutes or more. Furthermore, bouts of activity lasting 10+ minutes at all intensity levels were not impacted by hospitalizations. This discrepancy between low and high activity intensities may be due to a longer amount of time spent in lower intensity physical activity (100-759 counts/minute). Yet, hospitalization did not impact 10+ TPA minute bouts, in which LIFE participants participated in approximately one 10-minute bout of activity per week and even less periodic participation in long bouts at higher intensities (e.g., biweekly or monthly). As previous literature suggests, this bout length may describe an activity that is routine in an independent lifestyle (e.g. grocery shopping, retrieving mail, walking to a bank, visiting a doctor, etc.) and thus critical to maintain in life after a hospital event (80, 98). Also, little to no time was spent in long bouts of activity at intensities higher than LLPA, particularly in bouts of LMPA and HMPA. Individuals engage in these bout lengths less frequently in daily life routines that are often variable in length and may be more resistant to events such as hospitalizations. Our results suggest that older adults maintain the capability to perform physical activity following a hospitalization, despite spending long durations in the hospital, but may be at a more vulnerable state due to shrinking activity patterns and higher sedentary times. This is an important public health priority as hospitalized mobility-limited older adults are a vulnerable population in which interventions could be designed to preserve and perhaps bolster the capability to perform physical activity that has proven to reduce the risk of MMD.

The increases in sedentary patterns and decreases in physical activity may be a continuation of imposed bed rest often seen during hospitalization. Even short duration bed rest reduces muscle mass and function (64) and may worsen due to co-occurring sarcopenia (33). Not only does an intervening hospitalization affect activity patterns, but more time spent in the hospital leads to greater physical inactivity (25, 45, 76). We show that mobility-limited older adults do not regain pre-hospital activity levels which suggests that hospitalizations increase the risk of functional decline potentially through a loss in physical activity (25, 42, 43). This in turn negatively impacts the ability to maintain independence (24). Although, hospitalized participants appear to be on a new trajectory towards disability and functional loss, they paradoxically maintain activity at higher intensities, which may reflect preservation of routine activities necessary for self-care and independence in a community-dwelling setting. Future work is needed to implement efficient and immediate strategies to promote a sustained reduction in a sedentary lifestyle and provide support to increase physical activity back to pre-hospital levels in older adults on the cusp of being disabled.

There was no evidence that a long-term structured physical activity program reduced the negative effect that hospitalizations have on activity patterns. This is contrary to our hypothesis, which stated that a moderate-intensity structured physical activity intervention shown to reduce the risk of major mobility disability would attenuate the effect that a hospitalization is expected to have on activity. This is particularly puzzling because the LIFE study implemented a post-hospital re-engagement protocol for those randomized to the PA group. Though the effect of hospitalization did not change between PA and HE, we observed that there were significant intervention effects (8-10 minute decrease in short sedentary bouts and 4-6 minute increases in activity bouts) experienced by the PA group vs HE, independent of hospitalization. This suggests that the PA intervention did not change the magnitude of hospitalization's impact on bout patterns but improved recovery of activity afterwards. Even though hospitalized LIFE participants experienced a deleterious hospital effect, those hospitalized still increased levels of activity and managed sedentary behaviors better than those without structured physical activity. This supports post-hospitalization strategies to promote the integration of structured physical activity to combat functional decline and improve mobility after a hospitalization (26, 67, 107). While structured physical activity improves mobility, effects on daily lifestyle inactivity and activity patterns due to a hospitalization appears to be challenging to circumvent because those hospitalized in the PA intervention were still at lower levels of activity than those not hospitalized in PA. Future studies should focus on strategies within structured physical activity plans to improved recovery of post-hospital activity patterns, which may require earlier post-hospital care specifically tailored for patients to return back to regular daily activity levels as soon as safely able.

Strengths of this study include a large sample of racially-diverse mobility-limited men and women from eight field centers across the US for an average of 2.6 years with high retention and adherence rates. Patterns of physical inactivity and activity were measured objectively using a hip-worn accelerometer and repeated 3 more times over 2 years. Free-living accelerometer patterns were examined by volume, frequency, and intensity to reveal associations with intervening hospitalizations. Further, accelerometer cut-points used in this study combined traditional cut-points used in the literature (calibrated with adults 20+ years and older) and cut-points calibrated in older adult populations.

There are limitations to our study. We did not consider the reason for hospitalization in our analysis. However, the reason for hospitalization was diverse and no single type accounted for more than 15% of total hospitalizations in the LIFE study (71). Those who collected valid accelerometry tended to experience shorter-stay hospitalizations compared to the entire sample of LIFE participants who experienced any hospitalization so our results represent a smaller sample of mobility-limited older adults who live with less severe health conditions and had better physical function. The reason of hospitalization was not assessed in our study which may impact the effect by conditions specific to physical activity engagement and ability. Table C-1 shows that the reason for hospitalization (classified by organ class) in our sample was heterogeneous between both intervention groups except for hospitalizations for autonomic nervous system disorders (PA vs HE: 8 to 1, $p<0.04$). However, this class of hospitalization consisted of less than 3% of total hospitalizations in this analysis. Though measuring accelerometry periodically is one of the main strengths of this study, hospitalization effects on activity patterns lasting for less than 6 months may not have been captured in this analysis and may underestimate the negative hospitalization effect. Lack of knowledge regarding posture (e.g., sleep, sitting, etc.) may overestimate sedentary estimates by including standing and strength exercise behaviors. We also acknowledge the potential for residual confounding, specifically in regards to reasons for hospitalizations. The LIFE study is a randomized control trial but this analysis was designed as a prospective cohort with valid accelerometer to examine effect of intervening hospitalizations on activity patterns. To account for confounding, we adjusted for numerous factors which may affect both hospitalization reason (comorbidities) and inactivity/activity patterns longitudinally. Another limitation is the potential imbalance between groups where those in PA had more contact to study staff and therefore given more opportunity to report health events. To reduce this bias, we excluded hospitalizations which were not blinded to assessment staff, but it remains possible that participants were more likely to remember hospitalizations in the PA group. Additionally, the PA intervention incorporated a re-engagement protocol with strategies to bring hospitalized participants back into the intervention. The HE program did not implement these same strategies.

In conclusion, hospitalizations negatively impact post-hospital patterns of daily activity. Further, longer durations spent in a hospital setting leads to increased prolonged inactivity following a hospitalization. Those in the PA intervention decreased sedentary behavior in short bouts and increased activity towards longer and higher intensity bouts, regardless of being hospitalized or not. Still, engagement in a structured physical activity intervention, known to improve mobility, did not change the negative effect of hospitalization on patterns of daily activity. These findings help describe age-related declines in activity and further describe the irreversible trajectory towards inactivity that contributes to functional loss after hospitalizations. Future work is needed to develop interventions to promote immediate and sustained recovery of activity levels after hospitalization to help prevent mobility loss in the future. Additionally, future physical activity interventions should incorporate strategies to combat sedentary behaviors, while prioritizing reduction in prolonged inactivity immediately after a hospitalization. Finally, the results suggest that post-hospital home services should integrate strategies to increase participation in both short and long activity patterns at home to help prevent mobility decline, particularly among mobility-limited older adults who are at high risk of disability.

Table 5-1. Accelerometer cut-points used to derive metrics of physical inactivity and activity

Intensity	Bouts
Physical inactivity	
Sedentary behavior (SB): • < 100 counts/minute	1. Time spent in 1+ minute bouts (minute/day; total activity time) 2. Time spent in 10+ minute bouts (minute/day) 3. Time spent in 30+ minute bouts (minute/day) 4. Time spent in 60+ minute bouts (minute/day)
Physical activity	
Light physical activity (LLPA): • 100-759 counts/minute	1. Time spent in 1+ minute bouts (minute/day; total activity time)
High light physical activity (HLPA): • 760-1,040 counts/minute	2. Time spent in 2+ minute bouts (minute/day)
Low moderate physical activity (LMPA): • 1,041-2019 counts/minute	3. Time spent in 5+ minute bouts (minute/day)
High moderate physical activity (HMPA): • 2,020+ counts/minute	4. Time spent in 10+ minute bouts (minute/day)
Total physical activity (TPA): • 100+ counts/minute	

Table 5-2. Baseline participant characteristics by intervention group and hospitalization status over 24 months

	PA (n=669)			HE (n=672)		
	Hosp. (n=187)	No hosp. (n=482)	p	Hosp. (n=171)	No hosp. (n=501)	p
Age, mean(SD)	79.0 (5.4)	78.3 (5.2)	0.14	79.8 (5.2)	78.7 (5.2)	0.01
>= 80, n(%)	79 (42.3)	192 (39.8)	0.27	87 (50.9)	206 (41.1)	0.03
Female, n(%)	126 (67.4)	305 (63.3)	0.32	107 (62.6)	354 (70.7)	0.05
Non-Hispanic white, n(%)	139 (74.3)	358 (74.3)	0.68	144 (84.2)	376 (75.1)	0.04
College or higher education, n(%)	112 (65.5)	318 (63.5)	0.65	111 (59.4)	306 (63.5)	0.49
Married, n(%)	79 (42.3)	174 (36.1)	0.24	57 (33.3)	184 (36.7)	0.70
Annual income < $25,000	54 (28.9)	136 (28.2)	0.95	45 (26.3)	145 (28.9)	0.51
Body mass index, mean (SD)	30.3 (5.8)	30.1 (5.8)	0.68	30.1 (6.1)	30.6 (6.3)	0.44
Smoked 100+ cigarettes ever, n(%)	102 (54.6)	237 (49.2)	0.41	84 (49.1)	213 (42.5)	0.32
Modified Mini-Mental State Examination score[a], mean(SD)	91.4 (5.3)	91.9 (5.5)	0.33	91.8 (5.4)	91.6 (5.3)	0.60
Sought medical advice for depression in past 5 years, n(%)	28 (15.0)	69 (14.3)	0.75	28 (16.4)	57 (11.4)	0.17
Self-reported hospitalization in the past 6 months, n(%)	21 (11.2)	26 (5.4)	0.01	22 (12.9)	30 (6.0)	0.004
Comorbidities > 2, n(%)	57 (30.5)	115 (23.9)	0.18	63 (36.8)	114 (22.8)	0.001
Short Physical Performance Battery score < 8[b], n(%)	88 (47.1)	198 (41.1)	0.16	103 (60.2)	206 (41.1)	<0.001
400 meter walk < 0.8 m/sec, n(%)	111 (59.4)	287 (59.5)	0.97	77 (45.0)	299 (59.7)	0.001
Wear days, mean(SD)	8.0 (3.4)	8.0 (3.2)	0.89	8.1 (3.2)	7.8 (3.1)	0.87
Wear minute/day, mean (SD)	843.5 (120.2)	837.4 (109.8)	0.53	827.1 (85.8)	837 (116.3)	0.27
Minutes/day ≥ 760 counts, mean (SD)	25.6 (20.2)	28.3 (23.7)	0.18	22.4 (20.4)	29.8 (27.3)	0.001

Note: PA – physical activity; HE – health education; hosp. – hospitalized
[a] score range: 0-100 where higher scores indicate better performance
[b] score range: 0-12 where higher scores indicate better performance; scoring < 8 indicates poor functioning

Table 5-3. Hospitalizations by intervention group among participants who collected 3+ days of 10+ hours/day of accelerometry

	Physical activity (n=669)	Health education (n=672)
Participants hospitalized, n(%)	187 (28.0)	171 (25.4)
Hospitalization events, n(rate per participant)	299 (0.45)	247 (0.37)
0, n(%)	482 (72.1)	501 (74.6)
1, n(%)	120 (18.0)	121 (18.0)
2, n(%)	41 (6.1)	32 (4.8)
3+, n(%)	26 (4.0)	18 (2.7)
Baseline to 6 months, n(%)	77 (11.5)	55 (8.2)
6 to 12 months, n(%)	77 (11.5)	73 (10.9)
12 to 24 months, n(%)	145 (21.7)	119 (17.7)
Days hospitalized per participant, mean(SD)	1.6 (4.3)	1.3 (3.8)
Days hospitalized per hospitalized participant, mean(SD)	5.7 (6.4)	5.2 (6.0)
1-3 days, n(rate per participant)	94 (2.0)	93 (2.0)
4+ days, n(rate per participant)	93 (6.7)	75 (6.8)
Missing	0	3

Table 5-4. Descriptive baseline daily activity bouts by intervention group and hospitalization^

	Physical activity				Health education			
	None	1-3 days	4+ days	p	None	1-3 days	4+ days	p
Bout				Daily minutes, mean (SD)				
Sedentary								
1+	639.9 (110.1)	645.1 (118.2)	650.7 (96.3)	0.28	640.7 (106.8)	659.6 (99.1)	673.0 (99.9)	0.001
10+	485.7 (127.5)	497.2 (140.0)	511.2 (121.8)	0.03	486.5 (124.3)	514.8 (117.6)	544.7 (121.3)	<0.001
30+	299.5 (129.8)	313.7 (138.0)	329.4 (145.1)	0.01	298.3 (127.6)	328.4 (120.6)	366.7 (142.9)	<0.001
60+	151.3 (103.3)	162.9 (107.4)	179.3 (135.2)	0.004	148.9 (100.4)	167.5 (96.2)	209.0 (128.1)	<0.001
Total physical activity								
1+	187.4 (68.2)	172.1 (73.9)	152.1 (67.0)	<0.001	184.7 (65.0)	152.9 (57.8)	142.6 (60.3)	<0.001
2+	129.3 (52.3)	117.5 (57.0)	104.9 (54.1)	<0.001	127.1 (52.8)	103.0 (46.0)	96.1 (47.1)	<0.001
5+	45.3 (26.7)	41.1 (26.4)	36.4 (27.1)	<0.001	43.3 (26.7)	32.9 (22.6)	31.6 (22.0)	<0.001
10+	11.4 (11.8)	10.8 (10.3)	9.1 (10.8)	0.04	9.5 (11.0)	6.7 (8.1)	7.1 (8.0)	0.003
Low light physical activity								
1+	157.3 (53.6)	146.2 (57.6)	135.0 (56.5)	<0.001	157.9 (54.0)	136.2 (48.0)	124.7 (51.2)	<0.001
2+	116.4 (47.0)	106.3 (50.0)	98.0 (49.2)	<0.001	117.0 (47.0)	97.5 (42.8)	89.6 (44.3)	<0.001
5+	40.6 (25.5)	36.6 (24.0)	33.8 (25.8)	0.002	40.6 (31.7)	31.7 (22.2)	30.0 (21.6)	<0.001
10+	8.8 (10.5)	7.9 (7.6)	8.0 (10.3)	0.30	8.4 (9.9)	6.4 (8.1)	6.4 (7.7)	0.01
High light physical activity								
1+	12.6 (8.6)	10.7 (8.1)	7.8 (6.6)	<0.001	12.1 (9.1)	8.1 (6.2)	7.5 (5.8)	<0.001
2+	3.3 (3.1)	2.7 (2.5)	2.1 (2.6)	<0.001	3.0 (3.1)	1.8 (1.9)	1.7 (2.0)	<0.001
5+	0.4 (1.0)	0.2 (0.9)	0.4 (0.9)	0.76	0.2 (0.8)	0.1 (0.5)	0.1 (0.5)	0.33
10+	0.1 (0.6)	<0.1 (0.3)	0.1 (0.4)	0.40	<0.1 (0.4)	<0.1 (0.2)	<0.1 (0.4)	0.95
Low moderate physical activity								
1+	13.5 (11.8)	11.6 (11.2)	7.8 (8.1)	<0.001	12.0 (12.4)	7.3 (7.0)	7.5 (8.7)	<0.001
2+	6.8 (7.6)	5.8 (6.9)	3.8 (5.8)	<0.001	5.5 (8.2)	2.9 (3.9)	3.4 (5.3)	<0.001
5+	2.4 (4.1)	2.3 (3.9)	1.5 (3.4)	0.03	1.6 (4.5)	0.7 (1.3)	1.1 (3.1)	0.07
10+	1.2 (2.9)	1.2 (3.0)	0.7 (2.4)	0.18	0.6 (2.9)	0.1 (0.7)	0.5 (2.1)	0.40
High moderate physical activity								
1+	4.0 (7.9)	3.6 (8.9)	1.6 (3.2)	0.003	2.6 (5.5)	1.3 (2.7)	2.4 (11.8)	0.20
2+	2.9 (6.7)	2.8 (8.0)	1.0 (2.8)	0.01	1.6 (4.6)	0.8 (2.1)	1.4 (7.5)	0.20
5+	1.9 (5.6)	2.0 (6.6)	0.6 (2.1)	0.05	0.9 (3.6)	0.3 (1.4)	0.4 (1.9)	0.07
10+	1.4 (4.7)	1.6 (6.0)	0.3 (1.3)	0.08	0.5 (2.5)	0.2 (1.2)	0.1 (0.1)	0.06

^cumulative days spent in a hospital setting

Table 5-5. Effect of hospital duration on daily accelerometer pattern changes (daily minutes) in mobility-limited older adults (beta coefficient (SEM))^

	Physical activity (PA)		Health education (HE)		Combined		p-interaction
	1-3 days	4+ days	1-3 days	4+ days	1-3 days	4+ days	
Sedentary time							
1+ minute bouts	8.6 (4.3)*	15.5 (4.5)**	5.9 (4.4)	16.8 (4.9)***	7.5 (3.1)*	16.2 (12.2)***,#	0.82
10+ minute bouts	10.1 (6.6)	18.8 (6.9)**	5.8 (6.6)	26.8 (7.4)***	8.0 (4.7)	22.0 (5.1)***	0.58
30+ minute bouts	10.5 (7.7)	17.0 (8.0)*	6.1 (7.8)	27.7 (8.8)**	8.5 (5.5)	21.3 (5.9)***	0.58
60+ minute bouts	6.2 (7.0)	12.5 (7.3)	-0.5 (7.1)	30.0 (8.0)***	2.9 (5.0)	20.2 (5.4)***	0.20
Total physical activity							
1+ minute bouts	-8.7 (4.0)*	-17.4 (4.2)***	-3.8 (4.2)	-13.7 (4.6)**	-6.5 (2.9)*	-15.9 (3.1)***,#	0.64
2+ minute bouts	-7.4 (3.3)	-12.6 (3.4)***	-2.6 (3.3)	-9.5 (3.7)*	-5.2 (2.3)*	-11.4 (2.5)***	0.56
5+ minute bouts	-3.9 (2.0)*	-5.3 (2.0)**	-1.7 (2.0)	-2.2 (2.3))	-2.9 (1.4)*	-4.4 (1.5)**	0.58
10+ minute bouts	-1.4 (1.1)	-1.9 (1.1)	-0.3 (1.0)	0.7 (1.2)	-0.9 (0.8)	-1.2 (0.9)	0.43
Low light physical activity							
1+ minute bouts	-7.2 (3.3)*	-10.0 (3.5)**	-2.1 (3.4)	-11.9 (3.8)**	-4.8 (2.4)*	-10.7 (2.6)***	0.57
2+ minute bouts	-7.1 (3.0)*	-8.5 (3.1)**	-2.0 (3.1)	-9.7 (3.4)**	-4.7 (2.1)*	-9.0 (2.3)***	0.52
5+ minute bouts	-4.2 (1.9)*	-3.5 (2.0)	-1.5 (2.0)	-2.7 (2.2)	-2.9 (1.3)*	-3.4 (1.5)*	0.73
10+ minute bouts	-2.0 (1.0)	-1.0 (1.1)	< -0.0 (1.0)	0.3 (1.1)	-1.0 (0.7)	-0.6 (0.8)	0.77
High light physical activity							
1+ minute bouts	-1.3 (0.6)*	-2.6 (0.6)***	-0.9 (0.6)	-2.0 (0.6)**	-1.1 (0.4)**	-2.4 (0.4)***,#	0.82
2+ minute bouts	-0.6 (0.3)*	-0.9 (0.3)**	-0.3 (0.2)	-0.5 (0.3)	-0.4 (0.2)*	-0.8 (0.2)***	0.81
5+ minute bouts	-0.2 (0.1)	-0.1 (0.1)	< -0.0 (0.1)	< -0.0 (0.1)	-0.2 (0.1)	-0.1 (0.1)	0.72
10+ minute bouts	-0.1 (0.1)	-0.1 (0.1)	< -0.0 (0.0)	0.0 (0.0)	< -0.0 (0.0)	< -0.0 (0.0)	0.72
Low moderate physical activity							
1+ minute bouts	-1.0 (0.8)	-3.5 (0.8)***	-0.8 (0.8)	-1.7 (0.8)	-0.9 (0.6)	2.8 (0.6)***	0.25
2+ minute bouts	-0.6 (0.6)	-2.3 (0.6)***	-0.4 (0.5)	-0.7 (0.6)	-0.5 (0.4)	-1.6 (0.4)***	0.10
5+ minute bouts	-0.2 (0.4)	-1.0 (0.4)*	-0.1 (0.3)	0.2 (0.3)	-0.1 (0.3)	-0.6 (0.3)*	0.06
10+ minute bouts	-0.1 (0.3)	-0.4 (0.3)	< -0.0 (0.2)	0.4 (0.3)	< -0.0 (0.5)	-0.2 (0.2)	0.05
High moderate physical activity							
1+ minute bouts	0.5 (0.6)	-1.0 (0.6)	-0.5 (0.5)	-0.5 (0.6)	< 0.1 (0.4)	-0.2 (0.4)	0.12
2+ minute bouts	0.6 (0.5)	-0.7 (0.5)	-0.3 (0.4)	0.5 (0.4)	0.2 (0.3)	-0.1 (0.3)	0.12
5+ minute bouts	0.6 (0.4)	-0.5 (0.4)	-0.2 (0.3)	0.2 (0.3)	0.3 (0.2)	-0.3 (0.3)	0.29
10+ minute bouts	0.7 (0.4)	-0.4 (0.4)	-0.2 (0.2)	< 0.1 (0.2)	0.2 (0.2)	-0.3 (0.2)	0.38

^Reference value is no hospitalizations (0 days). All models were adjusted for time (months), wear time, baseline accelerometer metric, age, sex, race/ethnicity, income, education, marital status, modified mini-mental status exam score (3MSE where 100 is highest cognition score), self-reported depression, body mass index (kg/m^2), smoked 100+ cigarettes ever, comorbidity status, previous hospitalizations in the past 6 months, gait speed < 0.8 m/s, and clinical site. Intervention status was added as a covariate in pooled models. PA vs HE p value represents the interaction of hospitalization x intervention. *p<0.05 **p<0.01 ***p<0.001; #p<0.05 for trend across hospital duration categories

CHAPTER 6
CONCLUSIONS

Summary

The central objective of this dissertation was to examine the interaction between a long-term structured physical activity intervention and the role intervening hospitalizations contribute to patterns of daily inactivity and activity in mobility impaired older adults at high risk of disability. Accelerometers provide the ability to measure physical activity objectively in free-living settings, providing a unique opportunity to assess this interaction which is an important public health issue for one of the fastest growing age segments in the US population (109). No prior studies have evaluated patterns of daily inactivity and activity in mobility-limited older adults.

The first contribution this dissertation provides to the current literature is the characterization of sedentary time and physical activity patterns typical to mobility-limited older adults. This is particularly important because mobility-limited older adults are at high risk of physical disability and loss of independence (61). Our findings suggest that mobility-limited older adults are generally sedentary through the day (77% of daily waking time) through the accumulation of short bouts (<30 minutes) rather than prolonged bouts of sedentary behaviors. Physical activity accumulated by mobility-limited older adults account for the rest of daily waking time (23%) and are largely accrued in short bouts (<5 minutes) of physical activity at the lowest intensity which consists of 80% of total daily physical activity. An added contribution is the characterization of long-term activity patterns post-hospitalization where baseline sedentary patterns were higher and activity patterns were lower with higher time spent in hospital settings.

The second contribution was the finding that mobility-limited older adults increased time spent in sedentary behaviors in mainly short bouts, but also long and prolonged bouts. Our findings suggest that changes in sedentary time partly explain declines in function, independent of physical activity engagement. Concurrently, total physical activity decreased over time, while the composition of total physical activity shifted from higher intensity physical activity to the lowest intensity of physical activity. Hospitalizations accelerated these aging effects primarily by further increasing time in short sedentary bouts and decreases shorter bouts of total physical activity. Longer bouts of sedentary time were not affected unless hospitalized older adults spent 4 or more days in the hospital. This was similar to longer bouts of higher intensity physical activity except for bouts patterns at the highest intensity of physical activity and 10+ minute bouts of activity at any intensity. This indicates that the capability to perform physical activity at any intensity remained intact after an intervening hospitalization but this adverse event conferred deleterious effects on patterns of daily activity. Coupled with our findings that increase in sedentary time contribute to functional decline and that hospitalizations trigger a new trajectory towards overwhelming physical inactivity and shrinking activity beyond normal aging, we add to current knowledge to help describe the degree to which hospitalizations precipitate irreversible functional loss and future transition into disability (41-43).

The third contribution this dissertation provided was the evaluation of a structured, moderate intensity physical activity intervention's effect on patterns of daily activity. The intervention had small but beneficial effects on patterns of activity in mobility-limited older adults. This is important because sedentary behaviors have been associated with adverse health outcomes for which older adults are at high risk (29, 51, 62, 64, 75, 80). Because we found that sedentary changes were associated with changes in physical function, it appears that the PA intervention may have beneficial effects on physical function through sedentary pattern reductions. Also, the PA intervention changed the composition of total daily activity by increasing HLPA, LMPA, and HMPA, which previous literature suggest are beneficial to mobility and health (52, 83, 86, 89). Despite these beneficial effects of the intervention, age-related decline in total activity was not eliminated in mobility-limited older adults. Lastly, the PA intervention did not attenuate the added negative effects of hospitalizations on subsequent increase in sedentary time and decrease in physical activity but did not exacerbate hospitalization's deleterious effects on activity patterns.

There are limitations to this study. First, activity patterns were examined only in older adults with mobility limitations and not those with high physical function or severe cognitive deficits, reducing the generalizability of the results to the entire older adult population. Second, this is the first study to assess accelerometer-derived outcomes but not all LIFE participants collected accelerometry for at least 3 days of 10+ hours of valid accelerometry. After comparing those with and without valid accelerometry, we found no differences across age, sex, race/ethnicity, and number of hospitalizations. We did find those without valid accelerometry had slightly lower 3MSE scores (-1.6 average score, $p<0.001$) and higher hospitalization stays (+2.3 average days, $p=0.02$) when compared to those with valid accelerometry. However, cognition between those with and without valid accelerometry remained >90 (out of 100) and hospitalization stay differences were detected only during 12 to 24 months. Third, accelerometer outcomes were collected three times in 6-month intervals, and then a 12-month interval. These intervals may not fully capture in accelerometer-determined activity changes due to less severe hospitalization, but this bias is reduced using a comparison group. Lastly, accelerometer-derived sedentary time does not distinguish between postural positions, possibly capturing non-sedentary activities such as standing and strengthening exercises but intervention comparisons reduce this estimation bias.

An important strength of this study was the inclusion of mobility-limited older adults recruited from urban, suburban, and rural settings through 8 centers spanning across the United States. Further, LIFE participants represent an understudied portion of the population not typically examined in a randomized control trial setting. Though this study is not generalizable to adults 70 years of age and older, it focused on a vulnerable group of older adults at risk for mobility disability. Lastly, this is the first study to repeat collection of accelerometry 4 times over a 2-year period.

In conclusion, a structured, moderate intensity physical activity intervention known to improve mobility in older adults had small but beneficial effects on sedentary pattern reduction which appear to be associated with increases in physical function measures. Also, the intervention increasing daily activity patterns by changing the intensity composition of daily activity patterns (mainly low intensity short bouts) to higher intensities and longer bouts. However, this did not eliminate overall decline in total physical activity. Lastly, the PA intervention was not capable in attenuating accelerated increased physical inactivity (short and long bouts) and decreases physical activity after hospitalization.

Future Directions

Further work is needed to explore whether moderate-intensity PA replaces sedentary time and how the type of PA influences sedentary time. Developing ways to increase PA among older adults remains a key public health goal and future interventions should consider integrating a sedentary behavior reduction component to maximize health benefits in this vulnerable population. This dissertation helps describe the intersection between sedentary and physical activity patterns, exercise, and hospitalizations but only among mobility-limited older adults. There still remains a gap towards patterns of physical activity in other populations, particularly among those who are disabled who may be at higher risk for adverse health events such as hospitalizations.

The PA intervention was not meant to attenuate the effects of hospitalization. There needs to be future research which identifies specific reasons of hospitalizations which may affect daily activity patterns differently. For example, a hospitalization due to a leg injury may decrease daily time usually spent in grocery shopping more than a hospitalization due to an arm injury. Future work should also capture types of activities which are affected by hospitalizations and identify those which are preserved despite hospitalizations. This dissertation provides the initial evidence that more work is needed to develop immediate post hospital care which specifically promotes reducing sedentary behaviors and increasing total daily activity.

Identifying patterns of objectively collected daily inactivity and activity in mobility-limited older adults is unique to the literature. This work adds to the literature and helps build future work to detect patterns of activity which may indicate trajectories toward disability. Although the LIFE study was powered to detect the capability of the PA intervention to reduce the risk of major mobility disability, this secondary data analysis showed potential beneficial effects on sedentary and activity patterns. Future work should build on these findings by developing physical activity interventions to integrate efficient strategies to preserve and even bolster physical activity in free-living settings among those who are vulnerable to adverse health outcomes leading to loss of independence.

APPENDIX A

R CODE USED TO GENERATE ACCELEROMETER VARIABLES

```
##call libraries

library(accelerometry)
library(PhysicalActivity)

wide <- data.frame()
filelist <- dir("E:/LIFE datasets/Updated LIFE data_R data format/second_data/")
for (i in filelist)

{
load(paste("E:/LIFE datasets/Updated LIFE data_R data
format/second_data/",i,sep=""))
mydata <- AC.1s

mydata1m = dataCollapser(mydata, TS = "TimeStamp", col = "axis1", by = 60)

data1m = wearingMarking(dataset = mydata1m,

                    frame = 90,

                    perMinuteCts = 1,

                    TS = "TimeStamp",

                    cts = "axis1",

                    streamFrame = NULL,

                    allowanceFrame = 2,

                    dayStart = "00:00:00",

                    dayEnd = "23:59:59",

                    getMinuteMarking = TRUE,

                    newcolname = "wearing")

#Prior to deriving the participant level daily average metrics, outliers were identified
#and flagged.  Two kinds of outliers were defined in the LIFE study.

#first type
outlierFlag1 <- data1m$axis1 > 10000
```

```
#second type - first component to outlier...correcting for max x of 0
secondMax <- function(x) {
  if (max(x) > 0) {
    max( x[x!=max(x)])
  } else x <- 0
}
ag <- aggregate(data1m[, 2], list(data1m$days), secondMax)
secondMedian <- median(ag$x)
secondcutpoint <- median(ag$x) + 3500
outlierFlag2 <- data1m$axis1 > secondcutpoint

#second type - second component to outlier
outlierFlag3 <- FALSE #just a hack to make append work, not considered in the latter
code
for (d in 1:max(data1m$days)) {
  dayData <- data1m[data1m$days == d, ];
  thirdcutpoint <- ag[ag$Group.1 == d, ]$x + 1000;
  outlierFlag3 <- append(x = outlierFlag3, values = dayData$axis1 > thirdcutpoint)
}
data1m$outlierFlag <- (outlierFlag1 | outlierFlag2 | outlierFlag3[2:length(outlierFlag3)])

#created a 0/1 wear indicator
data1m$wearindicator[data1m$wearing == "nw"] <- 0
data1m$wearindicator[data1m$wearing == "w"] <- 1
data1m$wearindicator[data1m$outlierFlag == TRUE] <- 0

#Wear and non wear times summarized by day
if (is.element("w",data1m$wearing) == TRUE){
  mySummary <- summaryData(data1m, validCut=600, perMinuteCts=1,
markingString="w")
  validDayUse <- (names(mySummary$validWearTimeByDay))
  numvalday <- as.double(validDayUse)
} else numvalday <- 0

if (is.element("nw",data1m$wearing) == TRUE){
  mynonSummary <- summaryData(data1m, perMinuteCts=1, markingString="nw")
  nonweartimes <-mynonSummary$wearTimeByDay
} else nonweartimes <- 0

##Bout analysis
#1+ bouts
sed1total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)
```

```
  if (length(v.sub$axis1) > 1) {
    sed.1bouts.flag <- accel.bouts(counts=v.sub$axis1, weartime=v.sub$wearindicator,
bout.length = 1, thresh.upper = 99)
    sed1 <- sed.1bouts.flag == "1"
    datased1 <- v.sub[sed1,]
    sed1day <- nrow(datased1)
  } else sed1day <- 0

  sed1total <- sed1total + sed1day
  rm(sed.1bouts.flag, sed1, datased1, sed1day)
}
sed1perday <- as.double(sed1total/length(numvalday))

#10+ bouts
sed10total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 10) {
    sed.10bouts.flag <- accel.bouts(counts=v.sub$axis1, weartime=v.sub$wearindicator,
bout.length = 10, thresh.upper = 99)
    sed10 <- sed.10bouts.flag == "1"
    datased10 <- v.sub[sed10,]
    sed10day <- nrow(datased10)
  } else sed10day <- 0

  sed10total <- sed10total + sed10day
  rm(sed.10bouts.flag, sed10, datased10, sed10day)
}
sed10perday <- as.double(sed10total/length(numvalday))

#30+ bouts
sed30total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 30) {
    sed.30bouts.flag <- accel.bouts(counts=v.sub$axis1, weartime=v.sub$wearindicator,
bout.length = 30, thresh.upper = 99)
    sed30 <- sed.30bouts.flag == "1"
    datased30 <- v.sub[sed30,]
    sed30day <- nrow(datased30)
  } else sed30day <- 0
```

```
  sed30total <- sed30total + sed30day
  rm(sed.30bouts.flag, sed30, datased30, sed30day)
}
sed30perday <- as.double(sed30total/length(numvalday))

#60+ bouts
sed60total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 60) {
    sed.60bouts.flag <- accel.bouts(counts=v.sub$axis1, weartime=v.sub$wearindicator,
bout.length = 60, thresh.upper = 99)
    sed60 <- sed.60bouts.flag == "1"
    datased60 <- v.sub[sed60,]
    sed60day <- nrow(datased60)
  } else sed60day <- 0

  sed60total <- sed60total + sed60day
  rm(sed.60bouts.flag, sed60, datased60, sed60day)
}
sed60perday <- as.double(sed60total/length(numvalday))

#calculate low light bouts: 100 to 759 cpm

#1+ bouts
lowlight1total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 1) {
    lowlight.1bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 1, thresh.lower = 100, thresh.upper = 759)
    lowlight1 <- lowlight.1bouts.flag == "1"
    datalowlight1 <- v.sub[lowlight1,]
    lowlight1day <- nrow(datalowlight1)
  } else lowlight1day <- 0

  lowlight1total <- lowlight1total + lowlight1day
  rm(lowlight.1bouts.flag, lowlight1, datalowlight1, lowlight1day)
}
lowlight1perday <- as.double(lowlight1total/length(numvalday))

#2+ bouts
```

```
lowlight2total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 2) {
    lowlight.2bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 2, thresh.lower = 100, thresh.upper = 759)
    lowlight2 <- lowlight.2bouts.flag == "1"
    datalowlight2 <- v.sub[lowlight2,]
    lowlight2day <- nrow(datalowlight2)
  } else lowlight2day <- 0

  lowlight2total <- lowlight2total + lowlight2day
  rm(lowlight.2bouts.flag, lowlight2, datalowlight2, lowlight2day)
}
lowlight2perday <- as.double(lowlight2total/length(numvalday))

#5+ bouts
lowlight5total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 5) {
    lowlight.5bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 5, thresh.lower = 100, thresh.upper = 759)
    lowlight5 <- lowlight.5bouts.flag == "1"
    datalowlight5 <- v.sub[lowlight5,]
    lowlight5day <- nrow(datalowlight5)
  } else lowlight5day <- 0

  lowlight5total <- lowlight5total + lowlight5day
  rm(lowlight.5bouts.flag, lowlight5, datalowlight5, lowlight5day)
}
lowlight5perday <- as.double(lowlight5total/length(numvalday))

#10+ bouts
lowlight10total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 10) {
```

```
    lowlight.10bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 10, thresh.lower = 100, thresh.upper =
759)
    lowlight10 <- lowlight.10bouts.flag == "1"
    datalowlight10 <- v.sub[lowlight10,]
    lowlight10day <- nrow(datalowlight10)
  } else lowlight10day <- 0

  lowlight10total <- lowlight10total + lowlight10day
  rm(lowlight.10bouts.flag, lowlight10, datalowlight10, lowlight10day)
}
lowlight10perday <- as.double(lowlight10total/length(numvalday))

#calculate high light bouts: 760 to 1040 cpm

#1+ bouts
highlight1total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 1) {
    highlight.1bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 1, thresh.lower = 760, thresh.upper =
1040)
    highlight1 <- highlight.1bouts.flag == "1"
    datahighlight1 <- v.sub[highlight1,]
    highlight1day <- nrow(datahighlight1)
  } else highlight1day <- 0

  highlight1total <- highlight1total + highlight1day
  rm(highlight.1bouts.flag, highlight1, datahighlight1, highlight1day)
}
highlight1perday <- as.double(highlight1total/length(numvalday))

#2+ bouts
highlight2total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 2) {
    highlight.2bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 2, thresh.lower = 760, thresh.upper =
1040)
    highlight2 <- highlight.2bouts.flag == "1"
```

```
    datahighlight2 <- v.sub[highlight2,]
    highlight2day <- nrow(datahighlight2)
  } else highlight2day <- 0

  highlight2total <- highlight2total + highlight2day
  rm(highlight.2bouts.flag, highlight2, datahighlight2, highlight2day)
}
highlight2perday <- as.double(highlight2total/length(numvalday))

#5+ bouts
highlight5total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 5) {
    highlight.5bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 5, thresh.lower = 760, thresh.upper =
1040)
    highlight5 <- highlight.5bouts.flag == "1"
    datahighlight5 <- v.sub[highlight5,]
    highlight5day <- nrow(datahighlight5)
  } else highlight5day <- 0

  highlight5total <- highlight5total + highlight5day
  rm(highlight.5bouts.flag, highlight5, datahighlight5, highlight5day)
}
highlight5perday <- as.double(highlight5total/length(numvalday))

#10+ bouts
highlight10total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 10) {
    highlight.10bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 10, thresh.lower = 760, thresh.upper =
1040)
    highlight10 <- highlight.10bouts.flag == "1"
    datahighlight10 <- v.sub[highlight10,]
    highlight10day <- nrow(datahighlight10)
  } else highlight10day <- 0

  highlight10total <- highlight10total + highlight10day
  rm(highlight.10bouts.flag, highlight10, datahighlight10, highlight10day)
```

```
}
highlight10perday <- as.double(highlight10total/length(numvalday))

#calculate low moderate bouts: 1041 to 2019 cpm

#1+ bouts
lowmod1total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 1) {
    lowmod.1bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 1, thresh.lower = 1041, thresh.upper =
2019)
    lowmod1 <- lowmod.1bouts.flag == "1"
    datalowmod1 <- v.sub[lowmod1,]
    lowmod1day <- nrow(datalowmod1)
  } else lowmod1day <- 0

  lowmod1total <- lowmod1total + lowmod1day
  rm(lowmod.1bouts.flag, lowmod1, datalowmod1, lowmod1day)
}
lowmod1perday <- as.double(lowmod1total/length(numvalday))

#2+ bouts
lowmod2total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 2) {
    lowmod.2bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 2, thresh.lower = 1041, thresh.upper =
2019)
    lowmod2 <- lowmod.2bouts.flag == "1"
    datalowmod2 <- v.sub[lowmod2,]
    lowmod2day <- nrow(datalowmod2)
  } else lowmod2day <- 0

  lowmod2total <- lowmod2total + lowmod2day
  rm(lowmod.2bouts.flag, lowmod2, datalowmod2, lowmod2day)
}
lowmod2perday <- as.double(lowmod2total/length(numvalday))

#5+ bouts
```

```
lowmod5total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 5) {
    lowmod.5bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 5, thresh.lower = 1041, thresh.upper =
2019)
    lowmod5 <- lowmod.5bouts.flag == "1"
    datalowmod5 <- v.sub[lowmod5,]
    lowmod5day <- nrow(datalowmod5)
  } else lowmod5day <- 0

  lowmod5total <- lowmod5total + lowmod5day
  rm(lowmod.5bouts.flag, lowmod5, datalowmod5, lowmod5day)
}
lowmod5perday <- as.double(lowmod5total/length(numvalday))

#10+ bouts
lowmod10total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 10) {
    lowmod.10bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 10, thresh.lower = 1041, thresh.upper =
2019)
    lowmod10 <- lowmod.10bouts.flag == "1"
    datalowmod10 <- v.sub[lowmod10,]
    lowmod10day <- nrow(datalowmod10)
  } else lowmod10day <- 0

  lowmod10total <- lowmod10total + lowmod10day
  rm(lowmod.10bouts.flag, lowmod10, datalowmod10, lowmod10day)
}
lowmod10perday <- as.double(lowmod10total/length(numvalday))

#calculate high moderate bouts: 2020+ cpm

#1+ bouts
highmod1total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)
```

```
  if (length(v.sub$axis1) > 1) {
    highmod.1bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 1, thresh.lower = 2020)
    highmod1 <- highmod.1bouts.flag == "1"
    datahighmod1 <- v.sub[highmod1,]
    highmod1day <- nrow(datahighmod1)
  } else highmod1day <- 0

  highmod1total <- highmod1total + highmod1day
  rm(highmod.1bouts.flag, highmod1, datahighmod1, highmod1day)
}
highmod1perday <- as.double(highmod1total/length(numvalday))

#2+ bouts
highmod2total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 2) {
    highmod.2bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 2, thresh.lower = 2020)
    highmod2 <- highmod.2bouts.flag == "1"
    datahighmod2 <- v.sub[highmod2,]
    highmod2day <- nrow(datahighmod2)
  } else highmod2day <- 0

  highmod2total <- highmod2total + highmod2day
  rm(highmod.2bouts.flag, highmod2, datahighmod2, highmod2day)
}
highmod2perday <- as.double(highmod2total/length(numvalday))

#5+ bouts
highmod5total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 5) {
    highmod.5bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 5, thresh.lower = 2020)
    highmod5 <- highmod.5bouts.flag == "1"
    datahighmod5 <- v.sub[highmod5,]
    highmod5day <- nrow(datahighmod5)
  } else highmod5day <- 0
```

```
  highmod5total <- highmod5total + highmod5day
  rm(highmod.5bouts.flag, highmod5, datahighmod5, highmod5day)
}
highmod5perday <- as.double(highmod5total/length(numvalday))

#10+ bouts
highmod10total = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  if (length(v.sub$axis1) > 10) {
    highmod.10bouts.flag <- accel.bouts(counts=v.sub$axis1,
weartime=v.sub$wearindicator, bout.length = 10, thresh.lower = 2020)
    highmod10 <- highmod.10bouts.flag == "1"
    datahighmod10 <- v.sub[highmod10,]
    highmod10day <- nrow(datahighmod10)
  } else highmod10day <- 0

  highmod10total <- highmod10total + highmod10day
  rm(highmod.10bouts.flag, highmod10, datahighmod10, highmod10day)
}
highmod10perday <- as.double(highmod10total/length(numvalday))

#number of sedentary breaks
totalsedbreaks = 0

for (v in validDayUse) {
  v.sub <- subset(data1m, data1m$days == v)

  num.sedbreaks <- accel.sedbreaks(counts=v.sub$axis1,
weartime=v.sub$wearindicator, thresh = 100)
  totalsedbreaks <- totalsedbreaks + num.sedbreaks
}
sedbreaksperday <- as.double(totalsedbreaks/length(numvalday))

#HID
hid <- unique(na.omit(as.numeric(unlist(strsplit(unlist(i), "[^0-9]+")))))

#dataframe to write wide format: HID, accel metrics, non-wear, valid days
wide <- rbind(wide, data.frame(HID = hid[1], validdays = length(numvalday), wearmin =
sum(mySummary$validWearTimeByDay)/(length(numvalday)), nonwearmin =
sum(nonweartimes[validDayUse], na.rm = TRUE)/length(numvalday), sedvol =
sed1perday[1], sed10bouts = sed10perday[1], sed30bouts = sed30perday[1],
sed60bouts = sed60perday[1], sedbreaks = sedbreaksperday[1], lowlightvol =
```

```
lowlight1perday[1], lowlight2bouts = lowlight2perday[1], lowlight5bouts =
lowlight5perday[1], lowlight10bouts = lowlight10perday[1], highlightvol =
highlight1perday[1], highlight2bouts = highlight2perday[1], highlight5bouts =
highlight5perday[1], highlight10bouts = highlight10perday[1], lowmodvol =
lowmod1perday[1], lowmod2bouts = lowmod2perday[1], lowmod5bouts =
lowmod5perday[1], lowmod10bouts = lowmod10perday[1], highmodvol =
highmod1perday, highmod2bouts = highmod2perday[1], highmod5bouts =
highmod5perday[1], highmod10bouts = highmod10perday[1]))
}

##load .RData - I will use this file to merge everything else to
load("E:/LIFE datasets/Updated LIFE data_R data
format/second_data/PID_VC_HID.Rdata")
total <- REF

#merging to dataset
combined <- merge(total,wide,by="HID")

write.table(combined, file = "E:/LIFE sedentary_main/1 Sedentary time and bouts/R
output/NEW LIFE-M code/LIFE_accelerometry_all visits_streamNULL.csv",
row.name=FALSE, sep=",")
```

APPENDIX B
R CODE USED TO GENERATE HOSPITAL VARIABLES

```
# Functions ----------------------------
findTheVisit <- function(ppt.ref, day) {
  prev.visit <- which.max(which(ppt.ref$checklist_days < day))
  as.character(ppt.ref$vc[prev.visit]) #+ 1 after prev.visit logical but was removed bc of
the way vc is coded 1 = f6 2=f12 3=f24 4=sv2
}

setwd("V:/Amal/LIFE/LIFE main/3 Hospitalization and accelerometry/Analysis/Version
2/Merging data/Matin/")

#variable.df is a reminder that created variable is a dataframe
# note that $ is to index columns, [row, column] indexes everything

df.ref <- read.csv("LIFE01b_ActivityStatus_v2_1_visit days_FU24_weardays.csv")
df.ref$events.hospitalevent <- 0
df.ref$events.lengthofstay <- 0
df.ref$events.days_recenthosp_fu <- NA
df.ref$events.days_recenthosp_fu_v2 <- 0
df.ref$events.accel_hosp_overlap <- 0
df.aux <- read.csv("LIFE04_SAE_v2_1.csv")
df.aux$vc <- "F24"

# Sort df.ref to place SV2 visits on top of F06
df.ref$maskid <- factor(df.ref$maskid)
df.ref$vc <- factor(df.ref$vc, levels = c("SV2", "F06", "F12", "F24"))
df.ref2 <- data.frame(matrix(nrow = 0, ncol = ncol(df.ref)))
for(maskid in levels(df.ref$maskid)) {
  ppt.ref.df <- df.ref[df.ref$maskid == maskid, ]
  ppt.ref.df <- ppt.ref.df[with(ppt.ref.df, order(ppt.ref.df$vc, decreasing = F)), ]
  df.ref2 <- rbind(df.ref2,
                   ppt.ref.df)
}
rm(ppt.ref.df, maskid)
df.ref <- df.ref2; rm(df.ref2)

##create a variable of # of hospitalizations before each assessment
for(i in 1:nrow(df.ref)) {
  print(paste("(", i, " out of ", nrow(df.ref), ") checked.", sep = ""))
  maskid <- df.ref$maskid[i]
  visit <- as.character(df.ref$vc[i])
  upperBoundDay <- df.ref$checklist_days[i]
  if((!is.na(upperBoundDay)) && (upperBoundDay > 0)) { #if upperbound is not NA and
greater than 0
    lowerBoundDay <- df.ref$checklist_days[i-1] #lowerbound is days from rand. - 1
```

```
   df.ref$events.days_recenthosp_fu_v2[i] <- df.ref$checklist_days[i] -
df.ref$checklist_days[i-1]

   ppt.df <- df.aux[df.aux$maskid == maskid, ] #selecting rows to preserve column data
   events.df <- ppt.df[ppt.df$daysevntn_eevl > lowerBoundDay, ] #prune
   events.df <- events.df[which(events.df$daysevntn_eevl <= upperBoundDay), ] #
prune, which gives the true indices of a logical objective, allowing for array indices
   events.df <- events.df[which(events.df$hospital_eevl == 1), ]
   if(nrow(events.df) == 0) {
     next()
   }
   df.ref$events.hospitalevent[i] <- sum(events.df$hospital_eevl[events.df$masked==1],
na.rm = T)
   los <- (events.df$disdays_ohos-events.df$admdays_ohos) #added
   df.ref$events.lengthofstay[i] <- sum(los, na.rm = T) #added
   ##created a variable that gives days from recent hospitalization to future FU
   recent <- NA
   if(!is.na(max(events.df$disdays_ohos))) {
     df.ref$events.days_recenthosp_fu[i] <- upperBoundDay -
max(events.df$disdays_ohos, fill=0) #catches hospitalizations that are even after 24
months if they overlap the 24 month accel. collection
     df.ref$events.days_recenthosp_fu_v2[i] <- df.ref$events.days_recenthosp_fu[i]
   }
   else {#if(is.na(max(events.df$disdays_ohos))) {
     df.ref$events.days_recenthosp_fu[i] <- NA
   }
  }
  ##created 1 or 0 variable which marks any overlaps between accelerometry collection
and hospitalization
  lowerDay <- df.ref$checklist_days[i] ##created new lower bounds based on FU visit
  upperDay <- df.ref$checklist_days[i] + df.ref$validdays[i] ##created new upper bounds
based on wear days
  if (!is.na(lowerDay) && (!is.na(upperDay))) {
   ppt.df <- df.aux[df.aux$maskid == maskid, ] #selecting rows to preserve column data
   events.df <- ppt.df[ppt.df$daysevntn_eevl > lowerDay, ] #prune
   events.df <- events.df[which(events.df$daysevntn_eevl <= upperDay), ]
   if(nrow(events.df) > 0 && sum(events.df$hospital_eevl[events.df$masked==1], na.rm
= T) > 0){
     df.ref$events.accel_hosp_overlap[i] <- 1
   }
  } else {
   df.ref$events.accel_hosp_overlap[i] <- NA
  }
}
```

```
for(i in 1:nrow(df.aux)) {
    print(paste("(", i, " out of ", nrow(df.aux), ") added.", sep = ""))
    maskid <- df.aux$maskid[i]
    ppt.ref <- df.ref[df.ref$maskid == maskid, ]
    df.aux$vc[i] <- findTheVisit(ppt.ref, df.aux$daysevntn_eevl[i])
}

df.aux.reordered <- df.aux[, c(1, ncol(df.aux), 2:(ncol(df.aux)-1))]

write.csv(df.ref, file = "LIFE01b_ActivityStatus_v2_1_visit days_hospitalevent_2.csv",
row.names = F)
write.csv(df.aux.reordered, file = "LIFE04_SAE_v2_1_vc_2.csv", row.names = F) ##be
careful bc events after f24 are labeled SV2 atm
```

APPENDIX C
HOSPITALIZATIONS BY INTERVENTION

Table C-1. Reason for hospitalization across intervention group

Hospitalization reason*	Physical activity n=299	Health education n=247	p value
	n (%)		
Musculo-skeletal system disorders	62 (20.7)	65 (26.3)	0.13
General cardiovascular disorders	48 (16.1)	31 (12.6)	0.25
Gastro-intestinal system disorders	42 (14.1)	22 (8.9)	0.06
Central & peripheral nervous system disorders	26 (8.7)	19 (7.7)	0.67
Respiratory system disorders	21 (7.0)	22 (8.9)	0.42
Urinary system disorders	16 (5.4)	13 (5.3)	0.96
Vascular (extracardiac) disorders	13 (4.4)	12 (4.9)	0.78
Whole body general disorders	14 (4.7)	11 (4.5)	0.90
Heart rate and rhythm disorders	10 (3.3)	12 (4.9)	0.80
Skin and appendages disorders	6 (2.0)	7 (2.8)	0.53
Metabolic and nutritional disorders	7 (2.3)	3 (1.2)	0.33
Autonomic nervous system disorders	8 (2.7)	1 (0.4)	0.04
Endocrine disorders	7 (2.3)	2 (0.8)	0.16
Myo-, endo-, pericardial and valve disorders	2 (0.7)	7 (2.8)	0.05
Liver and biliary system disorders	5 (1.7)	2 (0.8)	0.37
Platelet, bleeding & clotting disorders	2 (0.7)	4 (1.6)	0.29
Hearing and vestibular disorders	2 (0.7)	3 (1.2)	0.44
Red blood cell disorders	2 (0.7)	2 (0.8)	0.85
Female reproductive disorders	2 (0.7)	2 (0.8)	0.85
Neoplasms	2 (0.7)	2 (0.8)	0.85
Psychiatric disorders	1 (0.3)	1 (0.4)	0.89
Male reproductive disorders	0 (0.0)	2 (0.8)	0.12
Vision disorders	0 (0.0)	1 (0.4)	0.27
White cell and reticuloendothelial disorders	1 (0.3)	0 (0.0)	0.36
Secondary terms - events	0 (0.0)	1 (0.4)	0.27

*Based on MedDRA system organ class, listed in decreasing order

Table C-2. Baseline participant characteristics by hospitalization status and intervention over 24 months

	Hospitalized (n=358)			Not hospitalized (n=983)		
	PA (n=187)	HE (n=171)	p	PA (n=482)	HE (n=501)	p
Age, mean(SD)	79.0 (5.4)	79.8 (5.2)	0.15	78.3 (5.2)	78.7 (5.2)	0.31
>= 80, n(%)	79 (42.3)	87 (50.9)	0.10	192 (39.8)	206 (41.1)	0.68
Female, n(%)	126 (67.4)	107 (62.6)	0.34	305 (63.3)	354 (70.7)	0.01
Non-Hispanic white, n(%)	139 (74.3)	144 (84.2)	0.02	358 (74.3)	376 (75.1)	0.81
College or higher education, n(%)	112 (65.5)	111 (59.4)	0.23	318 (63.5)	306 (63.5)	0.86
Married, n(%)	79 (42.3)	57 (33.3)	0.14	174 (36.1)	184 (36.7)	0.98
Annual income < $25,000	54 (28.9)	45 (26.3)	0.86	136 (28.2)	145 (28.9)	0.60
Body mass index, mean (SD)	30.3 (5.8)	30.1 (6.1)	0.75	30.1 (5.8)	30.6 (6.3)	0.26
Smoked 100+ cigarettes ever, n(%)	102 (54.6)	84 (49.1)	0.50	237 (49.2)	213 (42.5)	0.10
Modified Mini-Mental State Examination score[a], mean(SD)	91.4 (5.3)	91.8 (5.4)	0.44	91.9 (5.5)	91.6 (5.3)	0.44
Sought medical advice for depression in past 5 years, n(%)	28 (15.0)	28 (16.4)	0.72	69 (14.3)	57 (11.4)	0.40
Self-reported hospitalization in the past 6 months, n(%)	21 (11.2)	22 (12.9)	0.22	26 (5.4)	30 (6.0)	0.16
Comorbidities > 2, n(%)	57 (30.5)	63 (36.8)	0.25	115 (23.9)	114 (22.8)	0.87
Short Physical Performance Battery score < 8[b], n(%)	88 (47.1)	103 (60.2)	0.01	198 (41.1)	206 (41.1)	0.99
400 meter walk < 0.8 m/sec, n(%)	111 (59.4)	77 (45.0)	0.97	287 (59.5)	299 (59.7)	0.001
Wear days, mean(SD)	8.0 (3.4)	8.1 (3.2)	0.73	8.0 (3.2)	7.8 (3.1)	0.47
Wear minute/day, mean (SD)	843.5 (120.2)	827.1 (85.8)	0.14	837.4 (109.8)	837 (116.3)	0.97
Minutes/day ≥ 760 counts, mean (SD)	25.6 (20.2)	22.4 (20.4)	0.13	28.3 (23.7)	29.8 (27.3)	0.36

Note: PA – physical activity; HE – health education
[a] score range: 0-100 where higher scores indicate better performance
[b] score range: 0-12 where higher scores indicate better performance; scoring < 8 indicates poor functioning

APPENDIX D
HOSPITALIZATION DESCRIPTIVES BY TIME INTERVAL

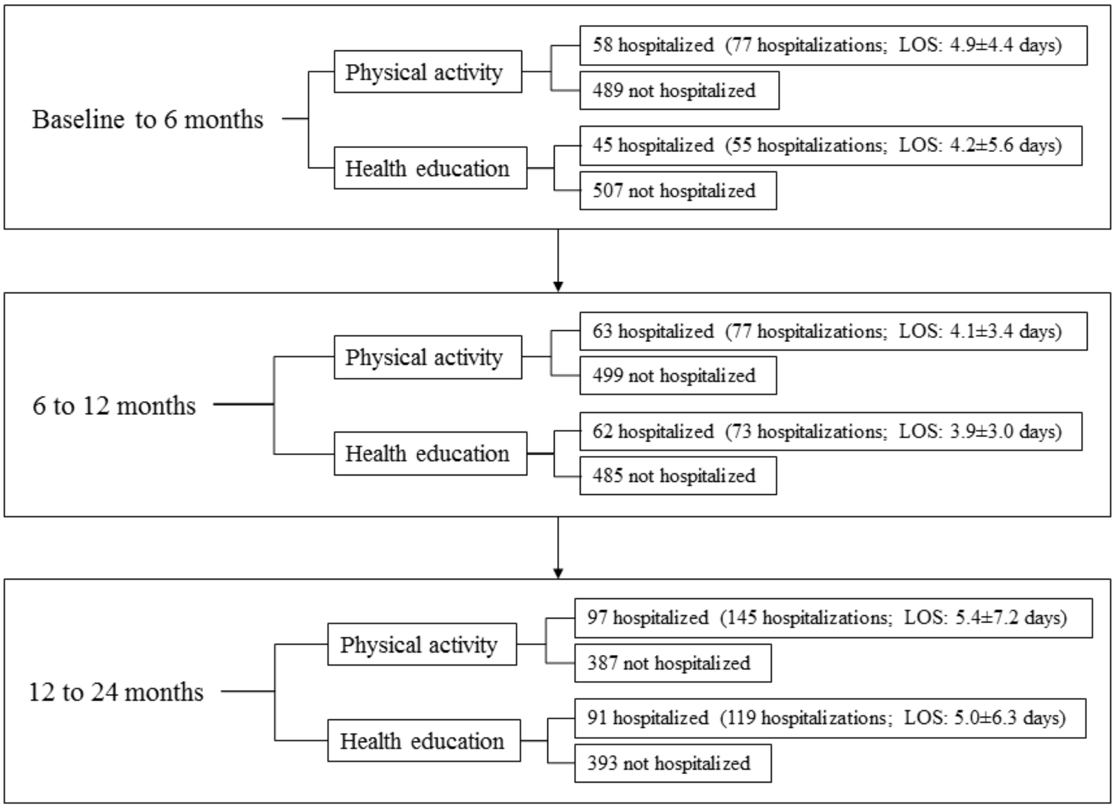

Figure D-1. Flow diagram of participants hospitalized within each time interval according to intervention. Note: LOS – length of stay (average days±SD)

APPENDIX E
CORRELATION ANALYSIS BETWEEN HOSPITALIZATION AND ACCELEROMETRY

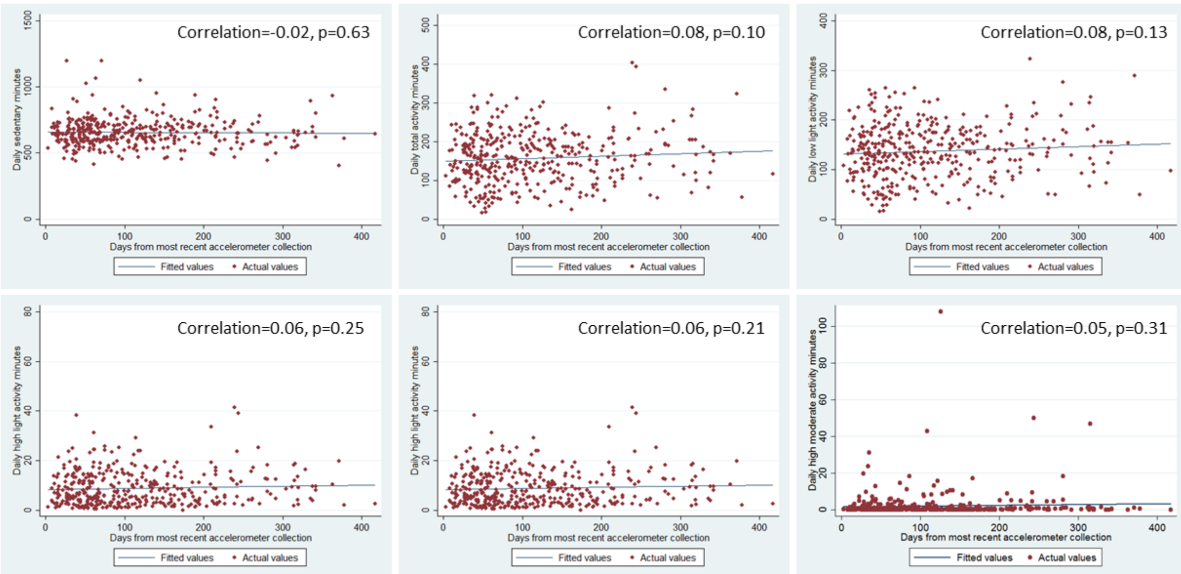

Figure E-1. Correlation between days from hospitalization and subsequent accelerometer collection and accelerometer outcome metrics

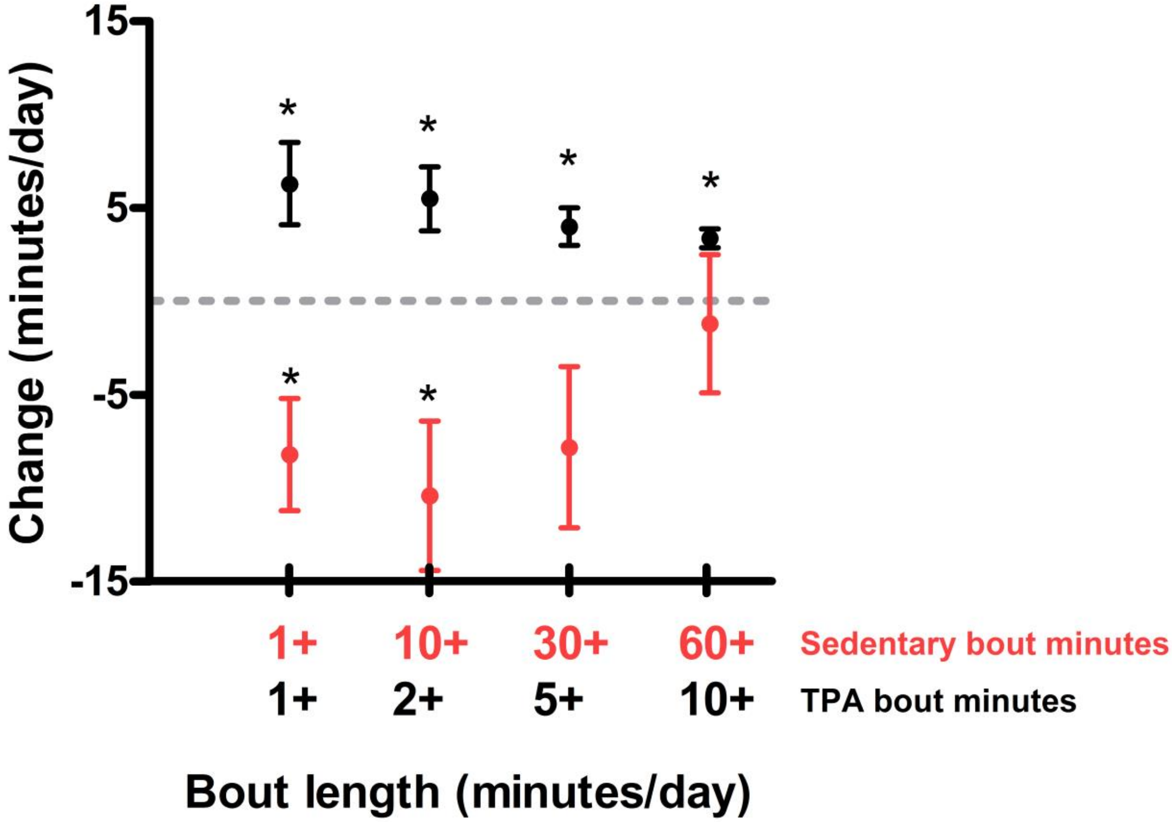

Figure E-2. The physical activity intervention effect (beta coefficient, SEM) on sedentary and activity bouts when compared to a health education program, independent of hospitalization over 2 years. Note: TPA – total physical activity. *p<0.05

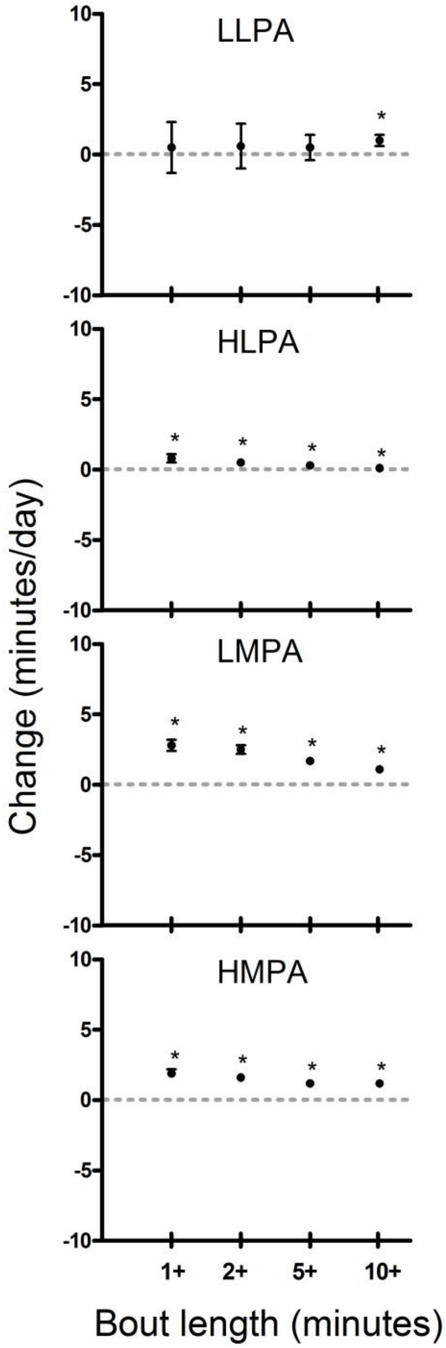

Figure E-3. The physical activity intervention effect (beta coefficient, SEM) on intensity-specific activity bouts when compared to a health education program, independent of hospitalization over 2 years. Note: LLPA – low light physical activity; HLPA – high light physical activity; LMPA – low moderate physical activity; HMPA – high moderate physical activity. *p<0.05

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BIOGRAPHICAL SKETCH

Amal Wanigatunga received his Ph.D. in epidemiology from the University of Florida in the spring of 2016. He also earned his bachelor's degree in chemistry and master's degree in public health. In parallel with his dissertation research, he worked as a graduate research associate with the Department of Aging and Geriatric Research at the Institute on Aging, University of Florida where he met with study participants, led clinical visits, trained incoming staff, and managed large data sets. His interests lie in physical function, disability, and physical activity among older adult populations and has presented numerous research projects at both local and national conferences. During his doctoral studies, his primary focus was on the measurement of physical activity, specifically with objective measures such as accelerometers.