Sedentary Behaviour Among Community Dwelling Older Adults

by

Michael J McCorry BA (Hons), MPhil

Faculty of Life and Health Sciences of Ulster University

Doctoral Thesis

Submitted in part fulfilment of the requirements for the award of Doctor of Philosophy

December 2020

I confirm that the word count of this thesis is less than 100,000 words

Contents

Dedication

To my wife, my children and my parents

Acknowledgements

I would like to acknowledge the support of a number of people, without whom this thesis would have been impossible to complete. Firstly, I would like to thank my supervisory team, Professor Marie Murphy, Dr Chris Bleakley and Dr Jacqueline Mair, for their patience, guidance and feedback over the past seven years; their expertise has made me a better researcher. In particular, I owe Professor Murphy a debt of gratitude for her guidance and support at various stages of my academic career over the past twenty-five years.

I am grateful to Ms. Julie Haydock in the School office and Ms Kate McMorris in the Doctoral College for their help with documentation and submission information and deadlines. I would like to thank Ms. Elaine Bell in the Research Office for her support with ethical approval applications and procedures. I would also like to express my gratitude to Ms. Mary-Rose Holman in the library for her assistance in completing the literature search for the systematic review.

My family have always been my greatest motivation. My wife Catherine and our four children, Ryan, Ciara, Áine and Joseph are a constant source of inspiration to me and I couldn't do any of this without their support. Also, to my late parents, Joseph and Úna McCorry, who always removed the obstacles and guided the way.

Finally, without participants, there would be no thesis, so I am particularly grateful to everyone who volunteered to participate in these studies.

Dissemination of findings

Peer Reviewed Publications

Abstract:

McCorry, M.J., Murphy, M.H., Bleakley, C. and Mair, J. (2018) The Effectiveness of Physical Activity and Sedentary Behaviour Interventions in Altering Sedentary Behaviour Among Older Adults: A Systematic Review. *The Lancet*, 392: S61.

Poster Presentations

McCorry, M.J., Murphy, M.H., Bleakley, C. and Mair, J. (2018) The Effectiveness of Physical Activity and Sedentary Behaviour Interventions in Altering Sedentary Behaviour Among Older Adults: Public Health Science: A National Conference, Belfast, November 2

“Those who think they have not time for bodily exercise will sooner or later have to find time for illness.”

—Edward Stanley, Earl of Derby, 1873

Abstract

Introduction

By 2030, the number of people globally aged over 60 years will surpass the number of children aged under ten (UN, 2017). Older adults are the least active section of the population and typically spend 60%-80% of their waking hours, sedentary (Harvey et al., 2015). They are also the section at most risk of mobility disability and functional impairment. The protective effect of physical activity on health may be reduced with prolonged bouts of sedentary behaviour, which is also an important determinant of physical function, frailty and falls in older adults (Landi et al., 2010; Peeters et al., 2010). The aim of this thesis was to investigate the relationship between physical activity, sedentary behaviour and physical impairment, and to develop a pilot intervention to reduce sedentary time in a group of community dwelling older adults.

Methods

A cross-sectional study examined whether sedentary behaviour or physical activity had the strongest association with physical impairment among community dwelling older adults. A systematic review of SB interventions was then done to determine which intervention mechanisms were likely to be successful with this cohort. The review informed the design and subsequent delivery of an education based, group supported sedentary behaviour reduction intervention that was practical, easy to administer and tolerable to a broad range of participants.

Results

Findings from the cross-sectional study suggested that the tests of physical function were more strongly associated with physical activity than with sedentary behaviour. However, when total sitting/ lying time was included in the analysis, there was little difference in the association. Participants were found to be sedentary approximately 60% of the waking day (9.5 $hrs.day^{-1}$) and to sit/lie/sleep a total of 18.3 $hrs.day^{-1}$. However total steps were recorded at 9745.day^{-1} and total MVPA at 168.7 $min.week^{-1}$, indicating a highly active cohort of participants. The systematic review demonstrated that the methodological quality of sedentary behaviour interventions was generally low and heterogeneity in study design was high. Although successful interventions used a broad range of behaviour change techniques to modify behaviour, evidence suggested that contextualising sedentary behaviour and targeting specific behaviours were also key ingredients. Findings from the intervention showed no statistical significance between groups over time for SB reduction. A small increase in total steps pre- to post-intervention of 3.5% was accompanied by a reduction in total objectively measured sedentary behaviour of 4.1%, suggesting that the behaviour may have been displaced by additional stepping activities. Total $steps/day^{-1}$ among the intervention group were 8431, indicating a high functioning group and limited opportunity for increased activity as a result of the intervention. Future sedentary behaviour interventions should include behaviour change functions that seek to raise awareness, educate and provide social or peer support for older adults. They should also target time spent in non-purposeful sedentary behaviours that are often conducted at home and when alone.

Conclusion

Older adults, particularly those for whom increased physical activity is difficult, may benefit from education-based, behaviour change interventions that seek to reduce time spent in prolonged sitting or lying postures. The ideal, or optimum, dose of sedentary behaviour reduction needed for positive clinical outcomes is still unknown but the findings suggest that even 1 $hr.day^{-1}$ of sedentary time substituted for LIPA is associated with better physical function among older adults. The findings also suggest that low burden interventions conducted where participants can avail of social support, may lead to higher levels of participant retention. SB research among older adults is still in its infancy and more research is needed to establish whether a dose-response relationship exists between SB and geriatric syndromes across the functional spectrum.

In summary the contributions of this thesis to the field of sedentary behaviour research are:

i. Total PA may be a more useful indicator of physical functional status for older adults than any subdivision of PA. Researchers should be careful to match the sensitivity and range of assessments undertaken to the expected physical functional ability of participants.
ii. Sitting/lying/sleeping may have a broader influence on physical functional status than SB alone. Due to the unique behavioural patterns demonstrated by older adults, research with this cohort should incorporate sit/lie/sleep measures in addition to SB measures where physical function is to be determined.
iii. Behaviour change strategies are an important ingredient in the development of SB reduction/ displacement interventions for older adults. Future investigations should use structured approaches (like the BCW) to design interventions that focus on

displacing non-purposeful sedentary time. Ideally, intervention designs should incorporate low-burden BCTs that educate older adults and use the influence of peers and group support to encourage self-efficacy and retention among participants.

Abbreviations and Acronyms

ADL	Activities of daily living
ANCOVA	Analysis of co-variance
ANOVA	Analysis of variance
APEASE	Affordability, practicability, effectiveness/cost effectiveness, side-effects/ safety, equity
BC	Behaviour change
BCT	Behaviour change technique
BCW	Behaviour Change Wheel
BMI	Body mass index
CB	Chris Bleakley
CHAMPS	Community Health Activities Model Programme for Seniors
CHD	Coronary heart disease
CI	Confidence interval
COM-B	Capability, opportunity, motivation, behaviour
IADL	Instrumental activities of daily living
IFS	Institute of Fiscal Studies
ISER	Institute of Social and Economic Research
IPH	Institute of Public Health
JM	Jacqueline Mair
LIPA	Light intensity physical activity
MM	Marie Murphy
MMC	Michael McCorry
MVPA	Moderate to vigorous physical activity
NI	Northern Ireland

NISRA	Northern Ireland Statistics and Research Agency
ONS	Office of National Statistics
PA	Physical activity
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RCT	Randomised Controlled Trial
ROI	Republic of Ireland
SB	Sedentary Behaviour
SBQ	Sedentary Behaviour Questionnaire
SBRN	Sedentary Behaviour Research Network
SD	Standard Deviation
SFT	Seniors Fitness Test
SPSS	Statistics Package for the Social Sciences
SPPB	Short Physical Performance Battery
TDF	Theoretical Domains Framework
TPB	Theory of Planned Behaviour
UK	United Kingdom
UN	United Nations
VPA	Vigorous Physical Activity
WHO	World Health Organisation

List of Figures

List of Tables

Notes to Access

I hereby declare that with effect from the date on which the thesis is deposited in Research Student Administration of Ulster University, I permit:

1. The Librarian of the University to allow the thesis to be copied in whole or in part without reference to me on the understanding that such authority applies to the provision of single copies made for study purposes or for inclusion with the stock of another library.

2. The thesis to be made available through the Ulster Institutional Repository and/or EThOS under the terms of the Ulster eTheses Deposit Agreement which I have signed.

Chapter 1

General Introduction and Review of Literature

1 Chapter 1

1.1 The Changing Demographics of Ageing

People can expect to live longer now than at any other time in history (Kontis et al., 2017). In 1920, life expectancy in the UK was 55 years for males and 59 years for females. In 2017 it was 79.6 years for males and 83.2 years for females. This increase has been cited as one of the global successes of modern medicine (Dilnot, 2017). The traditional pyramidal structure of ageing (Figure 1.1), where younger people outnumber older adults, has also changed as a result of falling birth rates, detection and management of chronic diseases and increased life expectancy (WHO, 2015). In 2017, the number of people globally aged 60 and over was 962 million, double the number recorded in 1980. This figure is set to double again by 2050 to 2.1 billion, by which time people aged over 60 will outnumber those aged 10-24 (UN, 2017). Domestically, 18% (12 million) of the UK population are now aged over 65 years and by 2030, this figure is expected to exceed 20% (ONS, 2019). In Northern Ireland, more than a quarter of a million people are aged over 65 years. This is set to rise by 56.3% by 2043 but more significantly, the number of people aged over 85 years is projected to rise by 106.4% within the same time period (NISRA, 2019). These figures describe the changing demographics of society, but they also highlight a need for additional social, occupational and health services to sustain quality of life in an ageing population.

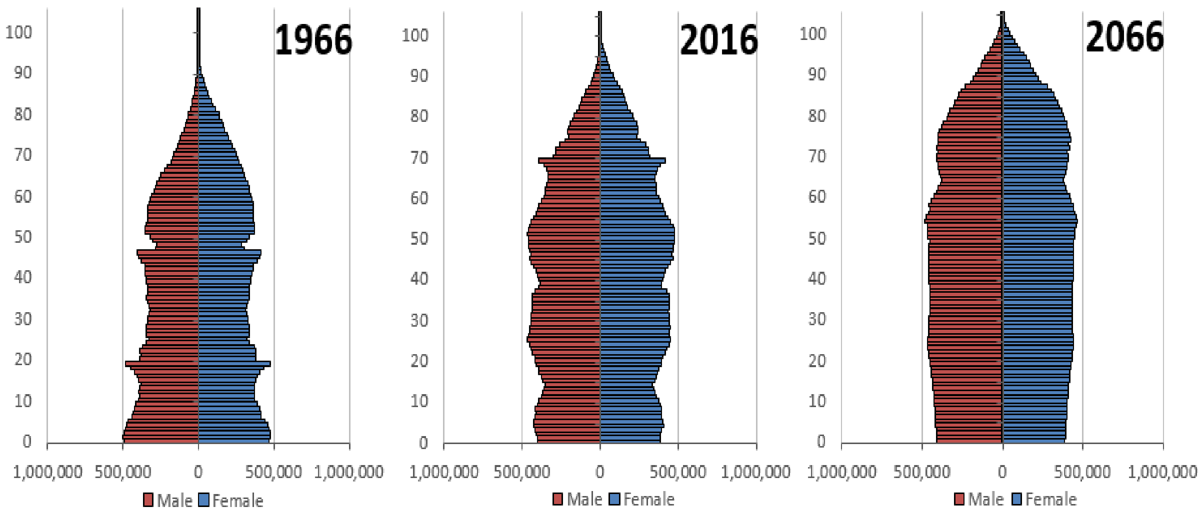


Figure 1.1 The changing global structure of ageing (source: www.ons.gov.uk

Although the overall trend is towards longer life, the same cannot be said for ‘healthy life expectancy’ (years of life free from disability), which has not changed in the UK since 2011 (Public Health England, 2018). Healthy life expectancy in England, from birth, currently stands at 63.3 years for males and 63.9 years for females (Kings Fund, 2018). Although females survive on average 3.6 years longer than males, they can only expect an additional 0.6 years disability-free (Kings Fund, 2018), suggesting that a greater proportion of years until death are spent in sub-optimal health. Currently, multimorbidity (the presence of two or more chronic health conditions) affects more than 50% of people aged over 65 years in the UK, and two thirds of those are aged over 80 years (Yarnall et al., 2017). The Office for National Statistics (ONS) (2018) report that older adults can expect to spend over half of their remaining years after the age of 65 with a disability or life-limiting condition. The number of older adults requiring assistance with at least one activity of daily living has risen from 1 in 8 to 1 in 7 since 2016. These figures highlight the importance of research into the impact of ageing on individuals and society.

1.2 A Global Focus on Healthy Ageing

Globally, there is a growing recognition of the social, economic and personal challenges associated with ageing. There is also a growing acceptance that disease and disability in later life can be reduced in duration, prevalence and severity with moderate changes to lifestyle (Bangsbo et al., 2019). In 2002, the 'Madrid International Plan of Action on Ageing' recognised the positive contribution of greater longevity on families (through financial support, childcare and household assistance) and on societies (through volunteerism and civic engagement). The plan encouraged governments to enable older people to participate more fully in society (UN, 2017). In 2012, the European Commission outlined an 'Active and Healthy Innovation Partnership' aimed at increasing healthy life expectancy by two years by 2020 (Lagiewka, 2012). One action group within the partnership was tasked with early diagnosis and prevention of physical and functional decline and frailty using targeted interventions that included physical activity. In 2015, the WHO Global strategy and action plan on ageing and health called for a commitment to action by policy makers within governments, regarding sustainability of provision, and equality of opportunity, for older people (WHO, 2015). As part of the strategy, the WHO committed to tackling traditionally held, yet invalid, public opinions of older adults as burdens on society or as economically redundant. The World Health Organisation (WHO, 2019) also designated 2020-2030 the 'Decade of Healthy Ageing' to encourage public and private sector organisations, academia and the media to collaboratively improve and enrich the lives of older adults and their communities.

A healthier ageing population benefits society. Recent increases in pension age, changes in traditional family structures and evolving social and technological environments mean that the contribution of older people to society is changing. In 2010 it was estimated that older adults made a net contribution in the UK (through tangible and nontangible economic transactions) of around £40 billion (Cook, 2011). In 2017, the Institute for Social and Economic Research (ISER, 2018) estimated the economic contribution of older adults to be approximately £160 billion (to include employment contributions, informal caring and volunteering) and stated that this figure was set to rise in future years.

1.3 Ageing and the Individual

The WHO (2015) define healthy ageing as, "the process of developing and maintaining the functional ability that enables wellbeing in older age". The ability to lead a full and independent life into old age is a universal goal. Chronology is traditionally used to define ageing and the United Nations typically use 60 years as the cut-point to define 'elderly' or 'older adult' in developed nations (UN, 2017). However, the proportion of physiological decline until death that is solely attributable to chronological ageing, irrespective of lifestyle, environment and energy expenditure is unclear (Arking, 2006). Sanderson & Scherbov (2005) suggest that biological age, which has no direct linear consistency, represents a better calculation of ageing in modern society than chronology. Indicators of biological age include the epigenetic clock (DNA methylation) and telomere length, which can predict the ageing process independent of chronology (Jylhävä et al., 2017). Significantly, both are influenced by an individual's environment and lifelong physical activity habits (two influential factors in human longevity).

Regardless of the definition, chronological ageing does have biological consequences that threaten the functional independence of older adults. The burdens of disease, disability and declining cognitive function tend to accompany the ageing process (Mason et al., 2016; Clegg et al., 2013; Hardman & Stensel, 2009). The presence of inflammation and disease resulting from progressive cellular damage throughout the lifespan causes multimorbidity (Nunes et al., 2016). This is more common in older people than in younger adults and inevitably leads to decreases in physiologic reserves (Ekelund et al., 2008). The following paragraphs outline some of the changes that may affect physical function and the performance normal activities of daily living in later life.

The microarchitecture of bone and other connective tissues begins to change with age. Intervertebral disks compress, posture tends to become poor and overall skeletal height reduces (Kenny et al., 2019). At this time, the rate of bone resorption begins to exceed synthesis, leading to osteopenia which, in combination with low levels of physical activity and poor diet, can lead to osteoporosis (Kenny et al., 2019). Osteoporosis is particularly prevalent among females who also experience a decrease in oestrogen concentration (which has a protective effect on bone mineral content) during menopause (Chastin et al., 2014).

Skeletal muscle isoforms (particularly type II fibres) alter the expression of strength and power with advancing age, mainly due to reduced muscle protein synthesis resulting from lower growth hormone secretion and changes in cell signalling (Kenny et al., 2019). This leads to sarcopenia (the age-related decline in skeletal muscle mass and muscle function), which is also heavily influenced by physical activity and diet. Sarcopenia is widely recognised as a geriatric syndrome and is associated with premature all-cause mortality among older adults. It affects males more acutely than females (Brown et al., 2016) and it is related to functional dependence, disability and increased risk of falls. The average rate of loss of muscle strength among normal healthy adults is approximately one percent per year after age 40 (Brown et al., 2016) but this accelerates with advancing age. In the Health ABC study, Goodpaster et al. (2006) found an annualised decline in the leg strength of 70 to 79-year-olds of 3.6% for men and 2.8% for women over a three-year period. Also, strength loss was three times greater in this study than the loss of lean mass, suggesting a decline in muscle quality, as well as size, with age.

Cardiovascular fitness (particularly $\dot{V}O_2$ max) declines in normal healthy adults at an average rate of 10% per decade after age 30 (Hagberg et al., 1985), a figure that is almost mirrored by the average decline in maximum heart-rate (Buskirk & Hodgson, 1987). Some of this reduction may be attributed to electrophysiological changes in the heart. However, a reduction in stroke volume also contributes significantly to a reduction in cardiac output (Kenny et al., 2019). In a study conducted by Proctor et al. (1998), increased sympathetic vasoconstriction and reduced vasodilator activity with age led to changes in peripheral blood flow of 20-30% in 55 to 68-year-old endurance trained athletes compared with 20 to 30-year-old athletes. Although these changes affected performance, they were somewhat diminished by a compensatory improvement in arterio-venous oxygen difference, which had a protective effect on endurance performance. Respiratory function (maximal expiratory ventilation and forced expiratory volume) declines with age as a result of reduced elasticity in lung tissue and the chest wall. However, outside of a diseased state, this is not thought to limit overall functional capacity (Kenny et al., 2019).

Ageing is commonly associated with a decline in cognitive function (Northey et al., 2018). Conditions like Alzheimer's disease and Dementia are more prevalent among older adults than younger people. Incidence rates of mild cognitive impairment rise significantly from age 55 years. The incidence of dementia rises from the age of 75 years and affects 44.7% of those aged 95 years or older (Northey, 2018). Though multi-neuropathological, cognitive impairment and the onset of dementia are also thought to be influenced by lifestyle and environment (Northey et al., 2018).

Although ageing is inevitable, the rate of age-related biophysiological and cognitive decline among normal healthy adults can be retarded with a combination of changes to lifestyle, diet and energy expenditure. The following sections outline some of the literature examining the effect of ageing and energy expenditure (specifically physical activity and sedentary behaviour) on physiological function.

1.4 Geriatric Syndromes, Frailty and Physical Impairment

The prevalence and incidence of health-related disease are known to rise in old age. However, other conditions that are not categorised under the traditional definition of disease, but which can significantly impact life expectancy and health-related quality of life (HRQUOL), are also more common among older adults. Some of these conditions (e.g. cognitive impairment, incontinence, delirium and frailty) have been described as 'Geriatric syndromes' due to their prevalence in old age (Inouye et al., 2007). They are also more common among older adults who are less physically active or more sedentary (Chastin, 2017). Frailty is a geriatric syndrome that describes a 'vulnerability to poor resolution of homeostasis leading to impaired function and negative health outcomes' (Clegg, 2013). Fried et al. (2001) developed a phenotype for frailty across five inter-related variables: unintentional weight loss, self-reported exhaustion, low energy expenditure, slow gait speed and weak grip strength, and found that adults classified as frail experienced more adverse health outcomes than participants classified as not frail.

Low energy expenditure at rest and during PA is a symptom of frailty that has been associated with functional decline and physical impairment (Bastone et al., 2019). In turn, physical impairment has previously been associated with twice the risk of mortality over no impairment among older adults (Bowling et al., 2014). Physical impairment can be defined as 'a dysfunction of the musculoskeletal and/or neurological body systems which affects the ability to move or co-ordinate movement' (http://education.qld.gov.au). It is linked with increased social isolation, loss of independence, reduced self-esteem and higher all-cause mortality (WHO, 2007; Clegg et al., 2013; Landi et al., 2016). Physical impairment stems from a gradual loss of physiologic reserves, reduced muscle mass (sarcopenia) and low bone mineral density (osteopenia) and leads to reduced functional fitness among those adults who engage in prolonged SB. Functional fitness is defined as 'having the physiological capacity to perform normal everyday activities safely and independently without undue fatigue' (Rickli & Jones, 1999). Symptoms of low physical function include reduced muscular strength, low walking gait speed, reduced stride length, low cardiovascular and muscular endurance and impaired mobility (Rickli & Jones, 1999; Frith & Davison, 2013; Landi et al., 2016).

Cross-sectional data linking geriatric syndromes with SB are beginning to emerge. Rosenberg (2016) found that every additional hour per day of SB was linked with an additional 21 s to complete a 400m walk. Jefferis et al. (2016) found a positive association between SB and falls risk among mobility impaired men in a one-year prospective study. Low physical function and low functional fitness are strong predictors of frailty and falls in older adults (Rickli & Jones, 2002; Landi et al., 2010; Peeters et al., 2010). Approximately 28-35% of people age 65 years and over experience an inadvertent fall each year, increasing to 32-42% for people aged over 70 years (Stalenhoef, 2002; WHO, 2007). A fall can lead to social isolation, loss of independence and reduced self-esteem. Unfortunately, it also leads directly or indirectly to death for 20% of the older adults hospitalised each year after an injurious fall (WHO, 2007). The financial implications of falls represent an increasing burden to the UK National Health Service. In 2015, the estimated total annual cost of falls to the NHS was £2.3 billion, up significantly from £1.6 billion in 2003 (NICE, 2013; NICE, 2018). Falls among the elderly do not always have a measurable economic impact or result in serious physical injury. However, the social and psychological consequences of a fall for older adults (increased fear, decreased self-efficacy and social isolation) can have serious implications for quality of life.

Balance impairment is a consequence of physical and functional impairment that is independently linked with falls risk (Rossat, 2010). Balance is defined as 'the ability to maintain the projection of the body's centre of mass (CoM) within manageable limits of the base of support, as in standing or sitting, or in transit to a new base of support, as in walking' (Winter, 1995). Balance has been described as a combination of three functions: the maintenance of posture, facilitation of voluntary movement and the recovery of equilibrium when externally disturbed (e.g. during a slip, trip or fall) (Mancini & Horak, 2010) and it is commonly assessed using clinical instruments like the Berg Balance Scale (Berg et al., 1992) or the 'Timed Up and Go' test (Podsiadlo & Richardson, 1991). Balance impairment means that older adults have greater difficulty activating the stabilising postural muscles when movement is executed and they tend to over- or under-respond when balance is disturbed (Howe et al., 2011).

Evidence suggests that older adults who are less sedentary experience greater postural balance, higher functional capacity and fewer falls (Mitchell et al., 2015). Physical activities that improve balance in older people are included in the UK Chief Medical Officers physical activity guidelines (Foster et al., 2019). Although intervention studies have demonstrated the contribution of increased PA to balance improvement and falls risk reduction (Rossat, 2010; Howe et al., 2011), the evidence is conflicting. A Cochrane collaboration review (Howe et al., 2011) found only weak evidence that exercise interventions are effective in improving clinical balance outcomes post-intervention. Furthermore, Zhao & Chung (2016) found that adults in the borderline stages of frailty were more likely to decrease their risk of falls from exercise interventions than people in either a high or low falls risk category, suggesting a ceiling effect of PA on the risk of falling.

Researchers have also begun to assess the effect of SB reduction on falls and physical function. Mitchell et al. (2015) reported that prolonged sitting in excess of eight hours per day was an independent predictor of falls over the previous 12 months in older adults. There are currently no studies that examine the link between SB, PA and geriatric-specific outcomes among older adults. Recent evidence shows that limited physical function among older adults may be a stronger predictor of mortality than chronic medical conditions (Copeland et al., 2017). Therefore, research is needed to quantify the harmful effect of increased SB, and the beneficial effect of SB reduction, on physical function in older adults.

1.5 Physical Activity, Morbidity and Mortality in Ageing

Physical activity (PA) can be defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Casperson et al., 1985). One of the most consistent findings in public health literature is the association between PA and health. Low PA is recognised alongside obesity and smoking as a determinant of life expectancy (Hamer et al., 2014) and is cited by the WHO (2018b) as the fourth leading cause of global mortality. It is thought to be responsible for one in six UK deaths and is estimated to cost the UK £7.4 billion annually (Public Health England, 2019). Evidence suggests that a physically active lifestyle can reduce the incidence of cardiovascular disease, coronary heart disease and stroke by 20-35%, depression by 30% and Dementia by up to 30% (Public Health England, 2019). Low PA is also a contributing factor in other diseases such as diabetes, colon cancer and breast cancer. Significantly, the incidence of these diseases in the last decade was higher in Ireland than in Europe and the rest of the world (Lee et al., 2012).

Seminal papers documenting changes in morbidity and mortality with age and physical health status (Morris et al., 1953; Paffenbarger et al., 1986) form the cornerstone of current investigations into energy expenditure, PA and functional capacity in old age. Jeremy Morris was one of the first researchers to investigate the link between the health hazards of low PA, sedentary living and coronary heart disease (CHD). His papers on postal workers, transport workers and civil servants demonstrated that CHD was more prevalent among men in 'sedentary' occupations e.g. bus drivers and civil servants, than among men who were more physically active e.g. bus conductors or postmen (Morris et al., 1958; Morris et al., 1980; Morris et al., 1990).

Epidemiological cohort studies have provided much of the current evidence supporting PA as part of healthy ageing. One of the best-known early, large-scale cohort studies was the Harvard Alumni Health Study (Paffenbarger et al., 1986) where researchers reported a dose-response relationship between PA and all-cause mortality over 12-16 years with 16,936 men. Questionnaires assessed PA among participants and the findings demonstrated a strong inverse relationship between energy expenditure and mortality. Participants who reported an energy expenditure of 3000-3499 $Kcal.wk^{-1}$ had a relative risk of death of 0.46 compared with those who reported under 500 $Kcal.wk^{-1}$. This study assessed PA subjectively (via questionnaire) but objective measures have consistently demonstrated a similar relationship. For example, Manini et al. (2006) used doubly labelled water in the Health ABC study to assess energy expenditure in 302 community dwelling older adults aged 70-82 years. In a six-year follow-up they found that death rates for participants in the high PA group were two thirds lower than those in the low activity group.

Although much of the seminal work in this field has examined the relationship between PA and health, the link between physical fitness, morbidity and mortality has also been investigated. Some of the first papers on ageing and fitness were published by Sid Robinson almost a century ago, who reported an age-related decline in VO_2 max in men aged 25-75 years and attributed the observation to physical ageing (Robinson, 1938). More recently, the Aerobics Centre longitudinal study (Blair et. al., 1989) found a protective effect for fitness on health over time. Researchers examined time to exhaustion on a treadmill against relative risk of death among 110,482 person-years of observation of 10,224 men and 3220 women with an eight-year follow-up. Participants in the lowest quintile of fitness had a relative mortality risk that was 3.44 times higher than the highest quintile, demonstrating the protective effect of cardiovascular fitness on health.

Lifelong participation is ideal, but the adoption of PA in the later stages of life can also benefit longevity. This was demonstrated in the English longitudinal study on ageing (Hamer et al., 2014). Researchers found a health benefit to becoming active in later life compared with remaining inactive, among 3454 disease free adults aged 63.7 $\pm$ 8.9 years assessed at eight years follow-up. Respondents who reported participating in moderate or vigorous physical activity were three to four times more likely to remain healthy with ageing compared with inactive participants. The authors suggested that one of the key mechanisms in health maintenance may have included sustained lower levels of inflammatory markers among those who remained physically active, leading to lower levels of chronic disease, cognitive decline and disability.

Human physiology is not the only aspect of health affected by PA in ageing. Depression is the most common mental illness among older adults. It affects 264 million people worldwide (WHO, 2020) and up to 15% of community dwelling older adults (Wei et al., 2019). Loneliness and social isolation are two of the highest risk factors for depression in this age group and the condition is associated with increased risk of reduced cognitive function, vascular Dementia, Alzheimer's disease, functional impairment and premature mortality (Catalan-Matamoros et al., 2016). Late life depression is also associated with 47-51% higher total healthcare costs among older adults (Wei et al., 2019). The role played by energy expenditure in the treatment of depression may be significant. A review of three meta-analyses (Matamoros et al., 2016) found that exercise and physical activity programmes led to a reduction in depressive symptoms among older adults. The authors recommended 45 $min.wk^{-1}$ of structured exercise over 10-14 weeks as a treatment for mild depression. Using an isotemporal substitution model, the NHANES study (Wei et al., 2019) replaced 30 $min.day^{-1}$ of sedentary behaviour (SB) with 30 $min.day^{-1}$ of moderate-to-vigorous physical activity (MVPA). Researchers reported lower somatic and cognitive depressive symptoms in 17,347 participants over a ten-year period.

1.6 The Recommended Dose of Physical Activity for Older Adults

Over the last century, industrialisation, mechanisation and machine-based labour has replaced much of the manual work previously done by people. It is estimated that adults in the Western world now typically expend 800 $Kcal.day^{-1}$ less energy than before World War Two (Hardman & Stensel, 2009). The increasingly sedentary nature of labour, overall reduction in physical activity and associated rise of hypokinetic illnesses have forced society to engineer energy expenditure back into daily life. Most of the main health advisory bodies now recognise that a minimum 'dose' of PA is required for a protective effect against hypokinetic disease. One hundred and fifty minutes of moderate intensity aerobic activity or 75 minutes of vigorous intensity activity per week (in bouts of at least ten minutes, over five or more days) is currently recommended (DHSC, 2019) to achieve these aims. In addition, these recommendations called for adults (particularly older adults) to engage in muscle strengthening and balance exercise, preferably in two bouts, totalling around 30 minutes each week. In the Republic of Ireland, the number of adults who achieve the minimum recommended 'dose' of 150 minutes of moderate aerobic exercise per week is approximately 33% (31% men, 34% women) (Healthy Ireland, 2018). This figure was also reported to reduce with age, highlighting the scale of the problem faced by organisations that seek to promote healthy ageing.

Although much of the focus on exercise and health has centred on MVPA, the contribution of light intensity physical activity (LIPA) to overall health and function among older adults has also been reported (Loprinzi et al., 2014; Foster et al., 2019). Older adults are more likely to be inactive or to display low levels of habitual PA due to reduced physical and/or cognitive function. However, the protective effect of LIPA on health in this age group has not been widely investigated (Copeland, 2019). If researchers are to intervene, then LIPA needs to be considered as the next step up in energy expenditure beyond simply standing. Also, increasing LIPA may prove a useful step towards MVPA for older adults who are inactive (Copeland, 2019).

The evidence above suggests that physical and mental decline can be slowed, temporarily halted or to some degree reversed in older adults who demonstrate higher levels of energy expenditure through PA and fitness. Recently, researchers have begun to evaluate the effect of very low energy expenditure and SB on ageing, health and disability. Currently, there is limited data on the effect of SB on the ageing process or on geriatric-specific issues like balance or physical function. This gap in knowledge should be addressed to evaluate the health impact of SB in ageing. The following sections examine the effect of SB, as a separate construct, on health and physical function in ageing.

1.7 Sedentary Behaviour, Ageing and Health

In 2017 the Sedentary Behaviour Research Network (SBRN) defined SB as 'time spent sitting, reclining and lying during waking hours, accompanied by energy expenditure below 1.5 METs' (SBRN, 2017). Older adults are known to be the least active section of the population and typically spend 60%-80% of their waking hours, or up to 9.4 hrs.day^{-1}, sedentary (Harvey et al. 2015). An individual can accumulate long periods of sedentary time in one day, in addition to the recommended amount of MVPA, and effectively be classified as sedentary but physically active at the same time (SBRN, 2017). SB is now recognised as an independent risk factor for metabolic dysfunction, reduced health-related quality of life and premature mortality (Hart et al., 2011; Santos et al., 2012; Gennuso et al., 2013; Engeroff et al., 2017) and national guidelines on healthy ageing now include recommendations to limit, reduce or disrupt periods of SB among older adults (DHSC, 2019). Figure 1.2 illustrates the energy expenditure continuum from sleep to vigorous activity.

Regular PA is recognised to have a protective effect on health, whereas prolonged SB is thought to counteract the positive effect of PA and accelerate secondary ageing (Booth, 2011). The 'Lifestyle Interventions and Independence for Elders' (LIFE) study (Fitzgerald et al., 2015) reported that each additional 25-minute period of sedentary time, independent of physical activity, was associated with a 1% increase in coronary heart disease among adults aged 79 $\pm$ 5 years.

In a review of reviews, deRezende et al. (2014) examined twenty-seven papers related to SB and health outcomes among older adults. They reported an association between SB, metabolic syndrome and all-cause mortality, regardless of time spent in PA. However, evidence for an association between SB and cancer or musculoskeletal disorders among adults was not clear. In the Lifestyle Interventions and Independence for Elders (LIFE) study, Fitzgerald et al. (2015) reported that each 25-minute period of additional sedentary time (independent of physical activity) was associated with a 1% increase in coronary heart disease among adults aged 79 $\pm$ 5 years.

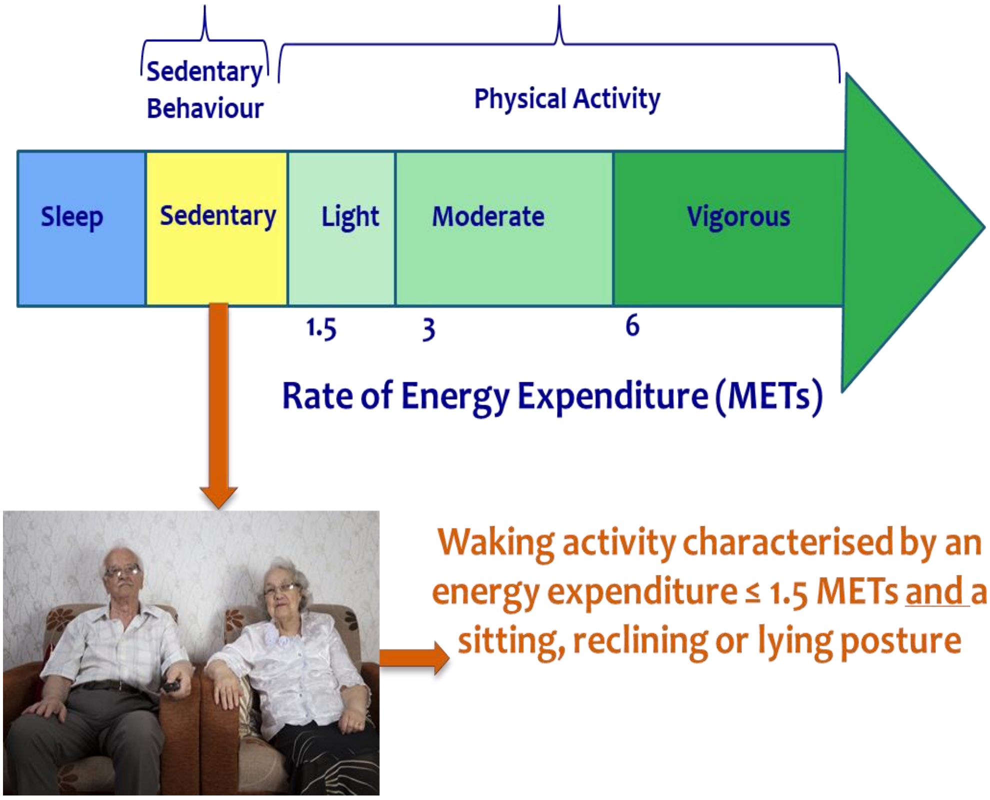


Figure 1.2 The energy continuum

(Source: Adapted from: https://www.sedentarybehaviour.org/what-is-sedentary-behaviour/)

Conversely, a recent systematic review and meta-analysis of 16 studies involving over 1 million adults found a protective effect for physical activity, such that 60-75 min.day^{-1} of MVPA eliminated the risk of death associated with prolonged SB (Ekelund et al., 2016). However, a more detailed examination of the data revealed that high levels of MVPA attenuated, but did not remove, the mortality risks associated with prolonged TV watching. This evidence suggests a need for further research investigating whether a trade-off in health-related outcomes exists between SB and PA among older adults, when controlling for the individual 'dose' (frequency intensity and duration) of each.

The way SB is accumulated is also linked to health outcomes (Aunger et al., 2018). Sedentary breaks and a reduction in sedentary bouts are important because prolonged sitting and prolonged standing have been reported as detrimental to health (Biddle et al., 2019). It has been suggested that 'the best posture is the next posture' (Biddle et al., 2019), indicating that frequent postural shifts are more important to health than simply replacing sitting with standing.

Evidence for a detrimental effect of prolonged SB on health extends to cognitive function. A systematic review of eight observational studies (Falck, 2017), using thirteen different measures of cognitive function in older adults, found an association between higher sedentary time and lower cognitive performance. However, the researchers reported that the specific attributable risk of SB to cognitive impairment was unclear.

Although SB has generally been categorised as a homogenous set of behaviours, there is evidence to suggest that not all SB is harmful to all aspects of health. Owen et al. (2011) distinguished between behaviours that were harmful to health and those that were not and categorised SB as either purposeful (e.g. involving social or cognitive engagement) or non-purposeful (e.g. screen time). The behaviours considered to be of greatest concern were non-purposeful, screen-focused behaviours and also involved prolonged sitting in the workplace (though workplace behaviours tend not to apply to retired older adults). Hallgren et al. (2020) suggested that context was an important consideration when evaluating the effect of SB on health. The authors made a distinction between 'passive' and 'mentally active' SB. Screen time, previously described by Owen et al. (2011) as non-purposeful, was sub-divided into mentally active (e.g. online puzzles, electronic reading) and therefore beneficial, and passive (e.g. tv watching, music listening while sitting or lying, sitting while commuting) and therefore harmful to health. Hallgren et al., (2019) previously reported a reduction in depression hazard of 5%, 13% and 19% respectively, after replacing 30 min.day^{-1} of passive SB with equivalent durations of mentally active SB, LIPA or MVPA.

Although there is clear cross-sectional evidence that prolonged SB is detrimental to health, the exact nature of the association remains unclear. Much of the current body of literature concerns school children and adults of working age. Few intervention or longitudinal studies have been conducted with older adults to determine associations between SB and geriatric-specific health outcomes. This thesis aims to further analyse the relative effect of, and relationship between, PA and SB on physical function with older adults. Also, it is not yet known which intervention designs work best with older adults and there are no minimum or recommended SB reduction guidelines for improved clinical outcomes in older adults. This thesis also aims to provide evidence-based recommendations for future SB intervention designs.

1.8 Determinants of Sedentary Behaviour in Older Adults

Until this decade, the word 'sedentary' was used to categorise a wide range of activities and behaviours that described the absence of PA. This led to considerable difficulty when comparing results across studies. For example, researchers variously defined 'sedentary' adults as those who: had a step count below 6000 steps per day (Petry et al., 2013); had not participated in moderate or vigorous PA for the last five years (Magistro et al., 2014); or who reported less than 20 $min.day^{-1}$ of at least moderate intensity exercise, three times per week (Sarkisian et al., 2007). SB is now recognised as a collection of similar behaviours that result in very low energy expenditure, performed in a sitting, reclining or lying posture (SBRN, 2017). The Sedentary Behaviour Research Network (SBRN) now define SB as 'time spent sitting, reclining and lying during waking hours, accompanied by energy expenditure below 1.5 METs' (SBRN, 2017)

In order to understand how to reduce SB in older adults, we need to understand its determinants. Older adults, particularly those aged over 65 years, are the section of the population at most risk of mobility disability and functional impairment (Harvey et al., 2015). Therefore, SB reduction is an important determinant of health outcomes. There is evidence to suggest that the determinants of SB among older adults are not the same as those among working age adults or children (Chastin et al., 2016). In particular, the move from a structured working environment to a less structured environment in retirement, with fewer time-critical commitments, has been associated with increased SB (Chastin et al., 2015). Barnett et al. (2014) also found that lower socioeconomic status in midlife was associated with a significant increase in television viewing time in later life. Self-reported health status and obesity have been linked with sedentary time and Ekelund et al. (2008) were able to accurately predict 5-year sedentary time from middle age adults, using BMI as the correlate. However, the evidence is not all negative. Chastin et al., (2015) suggested that maintaining a social role after retirement could lead to less time spent sitting and increased PA.

In 2011, Owen et al. presented an ecological model of SB and identified four domains where SB was most likely to occur (figure 1.3). They were leisure time, transport, occupation and household. Within each domain were multiple influences on behaviour, including social, individual, organisational/ community environmental and policy. The authors suggested that the physical and social contexts of SB were particularly important and suggested that an understanding of SB determinants in specific settings was an important consideration for SB intervention design.

More recently, Chastin et al. (2016) suggested that ecological approaches to SB had a limited ability to capture the complexity and association between determinants of SB. Instead, the authors proposed a 'system of sedentary behaviours' (SOS) framework for assessing and evaluating SB determinants. The determinants were clustered into: physical health and wellbeing; social and cultural context; built and natural environment; psychology and behaviour; politics and economics; home and institutional settings. Clusters were considered as synergists in the reduction of SB and factors were identified within clusters as having the 'combined highest modifiability and population level effect size in older adults (Chastin et al., 2016).

At the individual level, older adults have reported that living with pain and living in unsuitable environments were two significant determinants of time spent sitting (Chastin, 2015). Older women reported that pain and fatigue made standing difficult, while a lack of resting places and facilities outdoors discouraged them from engaging in more PA (Chastin, 2015). They also felt that conscious or unconscious social attitudes towards ageing resulted in community and family activities being designed for older adults to constantly sit (e.g. bingo or family social events).

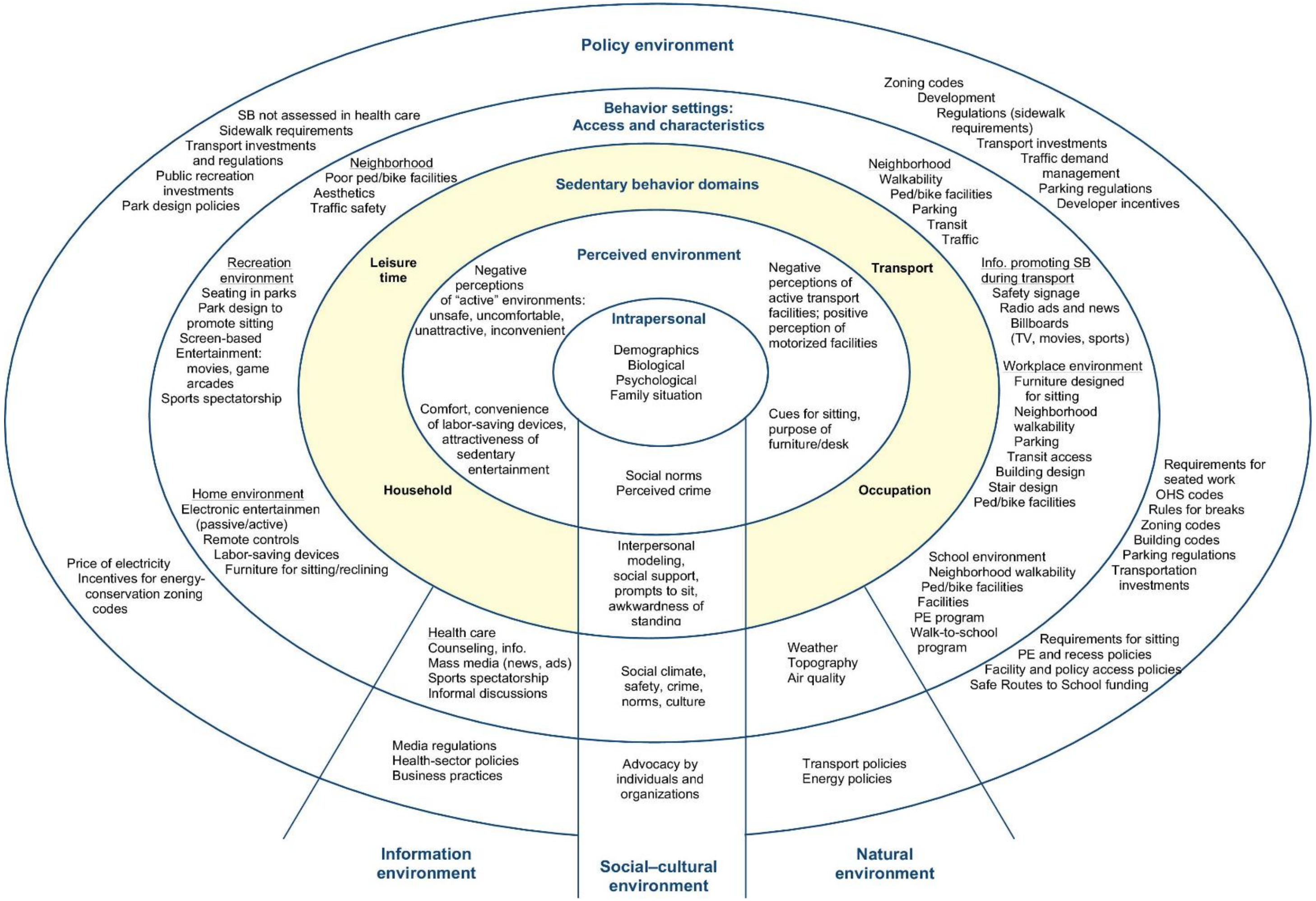


Figure 1.3 The ecological model of sedentary behaviour (source: Owen, 2011)

1.9 Behaviour Change, PA and SB.

There is considerable evidence that patterns of unhealthy behaviour throughout the lifespan contribute to increased levels of morbidity and mortality (Parkin et al., 2011). Therefore, interventions aimed at changing unhealthy behaviours are important to promote and improve population health. Behaviour change interventions have been described as 'coordinated sets of activities designed to change specified behaviour patterns' (Michie et al., 2011) and use 'active ingredients', known as behaviour change techniques (BCTs), to influence a proposed change. BCTs have been defined as 'observable and replicable components of behaviour change interventions' (Michie & Johnston, 2012). The use of BCTs to increase PA or reduce SB has its roots in social cognition theories (like the theory of planned behaviour (TPB); Ajzen, 1991) and have been applied to PA interventions through widely recognised models like the Transtheoretical Model of Behavioural Change (TTM) (Prochaska & DiClemente, 1983).

Although widely employed by practitioners in the health sciences, behaviour change interventions have been criticised for using approaches to change that either do not cover the range of behavioural influences for which the intervention is designed (Michie et al., 2011), or that fail to analyse which theories are best suited to influence behaviour change in a real world setting (Hagger & Weed, 2019). For example, Rhodes & Blanchard (2006) found that, within a TPB strategy, the removal of negative correlates of activity (e.g. watching TV) were beneficial to the promotion of other activities and reported that the intention-behaviour relationship between SB and PA were not the same, suggesting that different BCTs could be needed to displace SB than to increase PA. The behaviours considered to be of greatest concern were screen-focused behaviours and prolonged sitting in the workplace (though workplace behaviours tend not to apply to retired older adults). While this conclusion is evidence-based, Michie et al. (2011) suggest that TPB strategies, in general, fail to address other important behavioural influences such as impulsivity, habit, self-control and emotional processing, which could influence conclusions drawn from interventions based around a single theory.

A meta-analysis conducted by Davies et al. (2010) found that, although using a theoretical basis for behaviour change enhanced the effectiveness of interventions, less than a quarter of intervention studies at that time used a clear theoretical foundation at the design stage. In order to improve the use of theory to inform design, increase the application of BCTs to intervention design, and to create an evidence-based approach for study evaluation, Michie et al. (2011) developed the Behaviour Change Wheel and subsequently, a hierarchical taxonomy of 93 of the most common BCTs used by researchers (Michie et al., 2013). The taxonomy is used in conjunction with the Behaviour Change Wheel to design theory-based behaviour change interventions.

SB intervention designs require an understanding of how the behaviours can be changed and why (Gardiner et al., 2014). In 2011, Michie, Atkins & West published 'The Behaviour Change Wheel' (BCW). The publication synthesised nineteen of the most common frameworks of behaviour change into a model that could be used to design interventions in any domain.

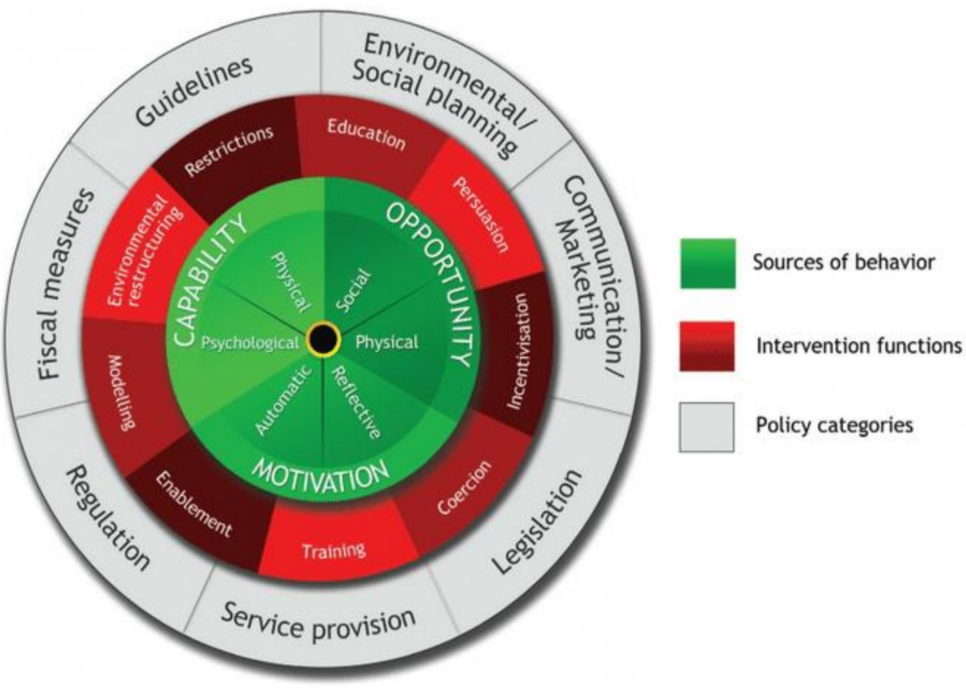


Figure 1.4 The behaviour change wheel (source: Michie et al., 2014)

The Behaviour Change Wheel (BCW) consists of three layers (figure 1.4). The inner layer uses a COM-B analysis (an individual requires '**C**' capability, '**O**' opportunity and '**M**' motivation to engage in any '**B**' behaviour) to determine sources of behaviour that could be used in targeted interventions. The second layer represents 'functions' (e.g. information or education), which indicate broad strokes by which an intervention could change behaviour. The outer layer represents seven types of policy that could be used to deliver the interventions. Although widely used, Ogden (2016) argued that the BCW and its associated taxonomy was a form of 'systemisation' and a limiter to theory variability. She warned that the widespread use of the BCW could limit the effectiveness of reducing patient variability, thereby reducing the researcher to the role of a technician rather than a professional.

The taxonomy that forms the basis of the BCW (Michie et al., 2013) was used to conduct a review of 38 sedentary behaviour reduction interventions by Gardiner et al. (2016). The authors reported that most promising strategies for future SB reduction interventions were based on environmental restructuring, persuasion and education. The most promising techniques used within the interventions were self-monitoring, problem solving and restructuring of the social or physical environment.

1.10 Intervening to Reduce SB in Older Adults

To date, most interventions with older adults have focused on total SB reduction, rather than distinguishing between purposeful and non-purposeful behaviours. Owen et al., (2011) suggested that effective interventions should concentrate on the most modifiable and harmful (non-purposeful) determinants of SB. Leask et al (2015) found that older adults were sedentary during leisure time and in their homes 70.1% of the day, making this an ideal target for interventions. The authors questioned whether interventions should target all SB or specifically, the passive and socially isolating periods, given both the causative association between social isolation and SB, and the well-established link between loneliness and depression in older adults. Therefore, SB reduction or displacement interventions could involve either a change in behaviour to something more purposeful, or a change in leisure activity to something more active involving social interaction.

Cross-sectional and cohort studies have demonstrated associations between SB, physical function and all-cause mortality. However, evidence that SB reduction leads to physical and cognitive improvement in older adults has only recently begun to emerge. Interventions have evolved to treat SB as a set of homogenous, modifiable behaviours that are independent to PA. This may have practical merit, given that older adults are often difficult to recruit to PA interventions, particularly those who are physically impaired (Copeland, 2019). There is a suggestion that older adults with impaired physical function may tolerate SB displacement better than increased PA (Copeland, 2019), making it a useful intervention tool. Self-efficacy and motivation have been cited as two of the main reasons for low recruitment to PA studies. Therefore, SB reduction could be used as a stepping-stone towards additional PA as physical function improves (Copeland, 2019). In a meta-analysis of 33 studies, Prince et al. (2014) found that interventions targeting sedentary time were more effective than those promoting PA among adults. The authors recommended adding a SB-specific element to PA interventions to achieve clinically meaningful reductions in sedentary time.

Historically, interventions have been designed to displace or reduce SB in several ways; via PA-specific interventions (Paw et al., 2006; Fanning et al., 2016; Naber et al., 2019), behavioural change techniques (BCTs) (Gardiner et al., 2011; Mutrie et al., 2012; Fitzsimons et al., 2013; Matson et al., 2018) or via a combination of both (Kallings et al, 2009; Chang et al., 2013; Burke et al., 2013; Roberts et al., 2019). Interventions that have used PA programmes alone (e.g. fitness classes) to displace SB have had little success. Researchers have used behaviour change techniques (BCTs) to either substitute SB with PA (Maher et al., 2017), or to focused on SB reduction with no reliance on PA (Matson et al., 2018; Naber et al., 2019). Maher et al. (2017) reported a subjectively-measured total weekday SB reduction of 117.7 min.day^{-1} with twenty-five older adults aged 60-95 over a two-week feasibility study. Matson et al. (2018) reported a significant reduction in SB habit strength in a 12-week SB intervention with 29 participants aged 60-89 years. They used BCTs based on social cognitive theory (Bandura, 1986), the ecological model (Sallis et al., 2008) and habit formation theory (Lally et al., 2011) to prompt breaks in sitting and to reduce overall sitting time. Naber et al. (2019) conducted an Occupational Therapy intervention using a Person-Environment-

Occupation model. This model was based on individual goal setting designed to increase motivation for engagement in meaningful activities among a group of participants in assisted living. Participants were aged 76-101 years and self-reported SB, using the Sedentary Behaviour Questionnaire (SBQ), decreased by an average of 1.5 $hrs.wk^{-1}$

The advent of wearable technology to monitor PA and SB has prompted research into the influence of technology on activity habits. Bravata et al. (2007) reported that the effect of wearing technology (in this case, pedometers) alone was responsible for a daily increase of 2000 $steps.day^{-1}$ among intervention participants. Roberts et al. (2019) used a technology-based intervention, combined with a structured exercise programme in an eight-week study with a 16-week follow-up. The study was designed to decrease SB and increase levels of non-exercise physical activity (NEPA) in a group of 40 adults aged over 60 years. The addition of technology to the intervention was reported to be responsible for 48 $min.wk^{-1}$ less total SB among the intervention group, suggesting that using body-worn monitors could have a reactive or independent intervention effect on participants.

1.11 Measurement of Older Adults' PA and SB

Valid and reliable tools are needed to assess the impact of SB on health and physical function. Additionally, the quantity and type of behaviour to be displaced needs to be accurately measured. Measurement tools need to be sensitive enough to capture quantitative changes in SB and accurate enough to contextualise these changes (a change in SB could either be a reduction in sitting/lying or a change from a more functionally harmful, non-purposeful behaviour to a less harmful, purposeful behaviour). There is currently no single measurement tool that can easily and accurately record both objective SB data and SB context in population-based studies. Body-worn monitors (e.g. Actigraph GT3X) are commonly used to provide objective, quantitative data on movement, that are also low in bias. However, manufacturers use proprietary algorithms to estimate PA and SB and these are not always directly comparable between devices. For example, the activPAL monitor records posture (via an inclinometer) along with movement (via an accelerometer) to provide information on time spent sitting and lying. Alternatively, the Actigraph GT3X uses an accelerometer with no inclinometer, and a threshold under 100 counts per minute, to signify SB (which indicates the absence of movement but cannot record seated or lying posture).

Self-report tools such as questionnaires are practical and inexpensive to use in large scale studies. However, they are also subject to bias and the data they provide may be more useful for recording SB trends or context than for accurately reporting SB quantities (Copeland et al., 2017). For example, the 'Community Health Activities Model Program' (CHAMPS) questionnaire was found to underestimate SB by 5.21 $hrs.day^{-1}$ when compared with Actigraph accelerometer data (Gennuso et al., 2015). Heterogeneity in questionnaire design can also be high, leading to problems comparing results across studies. For example, some questionnaires divide SB into contextual categories (e.g. screen time, transport, reading etc in the SBQ) but some do not (e.g. the IPAQ, which simply reports SB as total sitting time on weekdays and weekends). Difficulties using self-report tools extend further than response bias. Recall may also be a factor in the discrepancies between self-reported and objectively measured SB and PA with older adults. Herbolsheimer et al. (2018) warned that self-reported physical activity should be interpreted with caution in older adults since cognitive function could explain some of the differences reported between objective and subjective measurements. In addition, the concept of SB and the difference between physical inactivity and SB, may be unfamiliar to the intended participants. In a systematic review of older adults' perceptions of SB, Compernolle et al. (2020) found that many older adults did not know the difference between physical inactivity and SB. This may have implications for the type of self-report tools used with older adults and for the level or type of instruction provided to participants prior to completion of questionnaires.

In conclusion, self-report tools are inexpensive, easy to administer and could be appropriate for large, population-based studies. However, objective measurement tools are more expensive and time-consuming to administer but may be more precise. Both methods of data collection may be needed to provide accuracy, precision and context for SB, since not all sedentary behaviours e.g. reading or socialising, are regarded as unhealthful for older adults. (Copeland et al., 2017).

1.12 Measuring Physical Function in Older Adults

Physical function assessments can be viewed both as proxy health indicators and as predictors of health in older adults, given the link previously described between geriatric syndromes and mortality. They can also be used as indicators of physical decline and impairment. Guralnick et al. (1994) found that older adults who performed worst on a battery of physical function tests were four times as likely to suffer a disability within four years as those who performed best. Physical function can be assessed subjectively via self-report (e.g. Activities of Daily Living (ADLs) or Instrumental Activities of Daily Living (IADLs)) or objectively via physical testing batteries such as the Seniors Fitness Test (SFT) (Rickli & Jones, 1999) or the Short Physical Performance Battery (SPPB) (Guralnick et al., 1994). Functional assessments use indicators of physical function that are most commonly associated with impairment. For example, the Seniors Fitness Test (Rickli & Jones, 1999) incorporates lower body strength (30-second Chair Stand Test), upper body strength (30-second Arm Curl Test), aerobic endurance (6-minute Walk Test), lower and upper body flexibility (Chair Sit and Reach and Back Scratch Test) and agility and dynamic balance (the 8-foot Up and Go Test) in the test battery. Santos et al. (2012) found a negative association between functional fitness (using the SFT) and sedentary time among 117 males and 195 females aged 65-103 years. Peeters, (2014) found that participants in the most active group scored 24.5 points higher than the least active group (score scale was 0-100) in physical function tests over a 6-year cohort study. Participants who took fewer than seven hourly breaks per day in sedentary time had 2 to 5-fold increased odds for impairment in ADLs from a sample of 395 males and females aged 65-103 years (Sardinha et al., 2015).

Balance impairment is a geriatric syndrome that is influenced by sensory and musculoskeletal decline (Konrad, 1999), multiple disease processes and polypharmacy (Eibling, 2018). Balance disorders in older adults can lead to falls and injury. Some of the most commonly used clinical assessments of balance in older adults are the 'Timed Up-and-Go Test' (Podsiadlo & Richardson, 1991), the 'Functional Reach Test' (Duncan et al., 1990) and the 'Berg Balance Assessment' (Berg, 1992). The 'Timed Up-and-Go' records the time taken for a seated participant to stand, walk a fixed distance, turn and return to the original position. It measures dynamic balance and proprioception (nNodim & Yung, 2015). The functional reach test measures dynamic balance and requires the participant to reach forward with a straight arm at shoulder height without moving the feet. The Berg Balance Scale (appendix 7) is a 14-item scale in which participants perform seven tasks and seven elements of postural maintenance. It has been used in both institutional care and community settings but may be subject to ceiling effects with active older adults. After a systematic review of papers using the Berg Balance Scale, Lima et al. (2018) concluded that although the scale measures balance, evidence to support its use in falls prediction was insufficient and it should not be used alone to determine falls risk in older adults. Given the complex nature of physical function and balance, a battery of functional assessments may be needed to provide a more comprehensive view of an older adult's functional status.

1.13 Overall Aim and Objectives of the Thesis

The overall aim of this thesis was to investigate the effect of PA and SB on physical function in older adults, and to determine whether SB among older adults could be reduced or displaced with a targeted behaviour change intervention.

To achieve this aim, four main objectives were addressed in three main studies:

Objective 1: Study 1, Chapter 2 - A cross-sectional study investigating the relationship between SB, PA and physical function in older adults. This study would investigate whether PA and SB could be considered as separate constructs, independently linked with physical function in older adults.

Objective 2: Study 2, Chapter 3 – To conduct a systematic review and assess the effectiveness of SB interventions with older adults and evaluate the most effective mechanisms for SB reduction. The findings would then inform the design of a pilot randomised controlled trial (RCT).

Objective 3: Study 3, Chapters 4 & 5 – To develop and deliver a six-week RCT, designed to reduce SB among older adults in a community setting. A 4-week post-intervention follow-up assessment would evaluate whether any change in behaviour had been maintained.

Objective 4, Chapter 6 – To present a summary of the findings for each study along with recommendations for further research and an evaluation of the contribution of this thesis to current knowledge.

Chapter 2

Cross-Sectional Study

The Effect of Physical Activity and Sedentary Behaviours on Physical Impairment in Community Dwelling Older Adults

2 Chapter 2

2.1 Introduction

The demographics of ageing are changing rapidly. In 2017, 962 million people globally were aged 60 years or over. This number is forecast to grow to 2.1 billion by 2050 (UN, 2017) and by 2030, the number of people aged over 60 years will surpass the number of children aged under ten (UN, 2017). More than a quarter of a million people aged over 65 live in Northern Ireland (15.5% of the population). This number is projected to reach 24.7% of the population by 2039 (OFMDFM, 2015) and it highlights a growing need for social, occupational and health services to promote quality of life for an ageing population.

The ability to lead a full and independent life into old age is a universal goal. However, the burdens of disease, disability, declining cognitive function and socially significant conditions like Dementia and frailty tend to accompany the ageing process (Mason et al., 2016; Clegg et al., 2013; Hardman, 2009). In Northern Ireland alone, 38% of 65-74-year-old adults and 58% of adults aged over 75 years live with a mobility disability and 69% of people aged over 75 years suffer from a long-standing illness (OFMDFM, 2015). Consequently, there is a growing body of research into the diversity of health states apparent within the ageing process.

The relationship between physical fitness, health and physical function with ageing is well documented. However, the proportion of physiological decline that is solely attributable to chronological ageing, irrespective of lifestyle, environment and energy expenditure is still unclear.

A physically active lifestyle has long been associated with positive health outcomes (Hardman, 2009; WHO, 2007). There is strong evidence that elements of physical and mental decline can be slowed, halted or even reversed in older adults who demonstrate higher levels of energy expenditure and physical fitness (Manini et al., 2006; Hardman, 2009; Copeland et al., 2017). Conversely, low energy expenditure, particularly sedentary behaviour, is thought to be a strong predictor of poor physical and cognitive health in old age (Landi, 2010; Dogra et al., 2017). Older adults typically spend 60%-80% of their waking hours sedentary (Harvey et al. 2015) and this has been cited as an independent risk factor for metabolic dysfunction, reduced health-related quality of life and premature mortality (Hart, Ainsworth and Locke, 2011; Gennuso, 2013; Engeroff et al., 2017).

One of the main consequences of inactivity in older adults is physical impairment (Landi et al., 2010; Clegg et al., 2013), defined as 'a dysfunction of the musculoskeletal and/or neurological body systems which affects the ability to move or co-ordinate movement' (http://education.qld.gov.au). It is linked with increased social isolation, loss of independence, reduced self-esteem and higher all-cause mortality (WHO, 2007; Clegg et al., 2013; Landi et al., 2016). Physical impairment stems from the gradual loss of physiologic reserves, reduced muscle mass (sarcopenia) and low bone mineral density (osteopenia), leading to reduced functional fitness (Ekelund et al., 2018). Functional fitness is defined as 'having the physiological capacity to perform normal everyday activities safely and independently without undue fatigue' (Rickli & Jones, 1999) and is commonly assessed in older adults using instruments such as the 'Senior Fitness Test' (Rickli & Jones, 2002). Symptoms of low physical function include reduced muscular strength, low walking gait speed, reduced stride length, low cardiovascular and muscular endurance and impaired mobility (Rickli & Jones, 1999; Frith & Davison, 2013; Landi et al., 2016).

Physical and functional impairment are strong predictors of frailty and falls in older adults (Rickli & Jones, 2002; Landi et al., 2010; Peeters et al., 2010). Falls can result in social isolation, loss of independence and reduced self-esteem and lead directly or indirectly to death for 20% of the older adults hospitalised each year as a result of an injurious fall (WHO, 2007). Although falls among the elderly do not always have a measurable economic impact or result in serious physical injury, the social and psychological consequences for older adults (increased fear, decreased self-efficacy and social isolation) can have serious implications for quality of life.

Balance impairment is one consequence of physical and functional impairment that is independently linked with falls risk (Rossat, 2010). Balance is defined as 'the ability to maintain the projection of the body's centre of mass (CoM) within manageable limits of the base of support, as in standing or sitting, or in transit to a new base of support, as in walking' (Winter, 1995). Balance is commonly assessed with older adults using clinical instruments like the Berg Balance Scale (Berg et al., 1992) or the 'Timed Up and Go' test (Podsiadlo & Richardson, 1991). Physical impairment means that older adults tend to have greater difficulty activating the stabilising postural muscles when movement is executed and tend to over- or under-respond when balance is disturbed (Howe et al., 2011).

Evidence suggests that older adults who are habitually more active experience greater postural balance, higher functional capacity and fewer falls. Activities that improve balance in older people are included in the 2019 UK Chief Medical Officers physical activity guidelines

(Foster et al., 2019). However, there is conflicting evidence on the contribution of exercise-based interventions with older adults to the improvement of balance and reduction of falls risk (Rossat, 2010; Howe et al., 2011). Zhao & Chung (2016) found that adults in the borderline stages of frailty were more likely to decrease their risk of falls from exercise interventions than people in either a high or low falls risk category.

The relationship between physical activity and functional capacity in old age has been clearly demonstrated and low PA has been identified as an independent risk factor for morbidity and mortality. Recently, the relationship between PA and SB has come under scrutiny. Older adults experience greater reserves of physiological function when PA is maintained and there is evidence of a link between prolonged SB and ill health. However, whether SB (independent to PA) is a determinant or correlate of physical impairment in older adults, remains unknown. Gennuso et al. (2013) measured both variables in a cross-sectional study of older adults to investigate whether an interactive effect existed between them. They found that moderate-vigorous physical activity did not compensate for the negative associations found between sedentary behaviours and cardiometabolic risk factors. Also, sedentary behaviour was found to be a stronger predictor of cardiometabolic risk than levels of moderate to vigorous physical activity (MVPA) in this study.

Historically, the measurement of physical activity and sedentary behaviour has relied on subjective data derived from questionnaires (Atkin et al, 2012; Clark et al., 2011) which tended to categorise energy expenditure into activity 'domains' e.g. work-based or leisure-time activity, and sedentary time into contextual behaviours e.g. television viewing time or screen-based behaviours. Objective measurement of PA and SB has proved problematic and has involved either direct observation of participants (Lyden et. al., 2014) which can be time-intensive, or the use of a small, body-worn devices that incorporate an accelerometer (Hart, Ainsworth and Locke, 2011; Ellingson et al., 2013; Gardiner et al., 2011). Current generations of accelerometers use a signal, represented by an analogue voltage that is digitized by a twelve-bit Analog to Digital Converter (ADC) set (in the case of the Actigraph GT3X) to 30 Hz. The signal passes through a digital filter which is used to detect normal human motion. This is used to record changes in acceleration (counts) and thereby physical activity. In triaxial accelerometers like the Actigraph GT3X, counts in each of three axes indicate movement and increased counts per unit time indicate higher intensity physical activity. Counts are categorised by upper and lower cut-points that are used to define low, moderate and vigorous intensity movement. Cut-points for PA counts corresponding to light, moderate and vigorous PA have been validated for various populations and are now commonly used in research to standardise the comparison of PA levels between populations with similar characteristics (Heesh et al., 2018). Accelerometers tend to classify sedentary behaviour as time periods spent below a threshold value of counts e.g. 100cpm, deemed to represent the lowest intensity of physical activity (Atkin et al, 2012; Kozey-Kadle et al., 2010). However, this method of SB determination makes an arbitrary assumption about counts recorded when sitting or lying and about posture during periods of low energy expenditure. Therefore, depending on the cut-points used, accelerometers have been found to over- or underestimate sedentary time when compared with direct observation techniques (Matthews, 2012; Kim et al., 2015). Unless an accelerometer reading is accompanied by an inclinometer reading, low-count thresholds may not truly reflect SB because they cannot differentiate between upright (non-sedentary), sitting (sedentary) and supine (sedentary) positions. Low activity counts could simply indicate very light activity or inactivity performed while standing, particularly among older adults who tend to move more slowly and less frequently than their younger counterparts (Heesh et al., 2018). Recent innovations in wearable devices record movement with an accelerometer and posture via an integrated inclinometer (e.g. the activPal; Pal technologies Inc.), thus improving the accuracy of the device in measuring sedentary time (Winkler et al., 2016). However, limitations of these devices include an inability to distinguish waking from sleeping behaviour while sitting and differentiating the supine position from non-wear of the device.

Regardless of the limitations of individual devices, strong epidemiologic evidence points to health risks associated with prolonged sedentary time, independent of time spent in physical activity, for older people who maintain the recommended daily 'dose' of MVPA (Bauman et al., 2011). Thus far, no study has used reliable objective tools to measure the relationship between the physical activity 'dose' and sedentary time in older adults or to examine whether there is a link between sedentary time and physical impairment. Given the increasing rate of physical decline and frailty among older adults, it seems logical to investigate this relationship.

2.2 Aim of the Study

This study focused on the association between PA and SB (as predictor variables), and physical impairment (as the outcome variable). Both predictor variables have previously been linked in the literature with functional capacity, frailty, morbidity and mortality. The main aims of this study were:

1. To investigate which, of PA or SB, was more strongly correlated with physical impairment in independent, community dwelling older adults.

2. To investigate whether objectively measured SB, independent of physical activity, was associated with physical impairment.

2.3 Experimental Design

This was a cross-sectional study examining the association between two objectively measured predictor variables (PA and SB) and physical impairment. The study was approved by the Ulster University Research Ethics Committee (RGRN 14/0099, Nov. 2014). Key documentation including participant information sheets, recruitment sheets, health documentation and test protocols for this study can be found in appendices 1-9.

2.3.1 Sample Size

In a simulation study of the number of events per variable in logistic regression analysis, Peduzzi et al. (1996) recommended 15 participants per variable. In this study two predictor variables were used, indicating a total sample size of 30 participants, rising to 60 to account for potential dropouts or exclusions. In addition, based on the table of cut offs for statistical significance of r values - a sample size of 30 with a moderate correlation coefficient of ~r=0.25 was considered significant at P<0.05 (Peacock and Peacock, 2011).

2.3.2 Participants

Community dwelling older adults (n=54; age 70-79 years) were recruited from community-based organisations and faith-based groups in Northern Ireland and the Republic of Ireland via flyers, advertisements, word of mouth and informal meetings between November 2014 and June 2017. Initial expressions of interest were followed by a recruitment information sheet outlining the purpose and details of the study, the researchers involved and the supervisory team. This was followed by a participant information session one week later. The experimental design, protocols and risks were explained to participants at the meeting, after which queries were answered and informed consent was taken. At this time, participants were also asked to complete a health history questionnaire and were screened for inclusion and exclusion criteria.

The main exclusion criteria were as follows:

- Not willing or unable to participate (e.g. not signing an informed consent).
- Not living independently or living in supported living accommodation.
- Unable (physically or mentally) to receive and understand simple instructions on operation of measurement devices and descriptions of study parameters.
- Diagnosed diseases or conditions known to impair cognitive function and/or movement including: Parkinson's disease, stroke, M.S., amputation of upper or lower limbs, dementia, osteoporosis (causing movement impairment), rheumatoid arthritis (causing movement impairment), osteoarthritis (causing movement impairment), hip fracture and Alzheimer's disease (Howe et al., 2011).
- Habitual use of psychotropic medications.

Participants were permitted to withdraw from the study at any time without reason or justification. See Figure 2.1 for a flowchart of the experimental procedures.

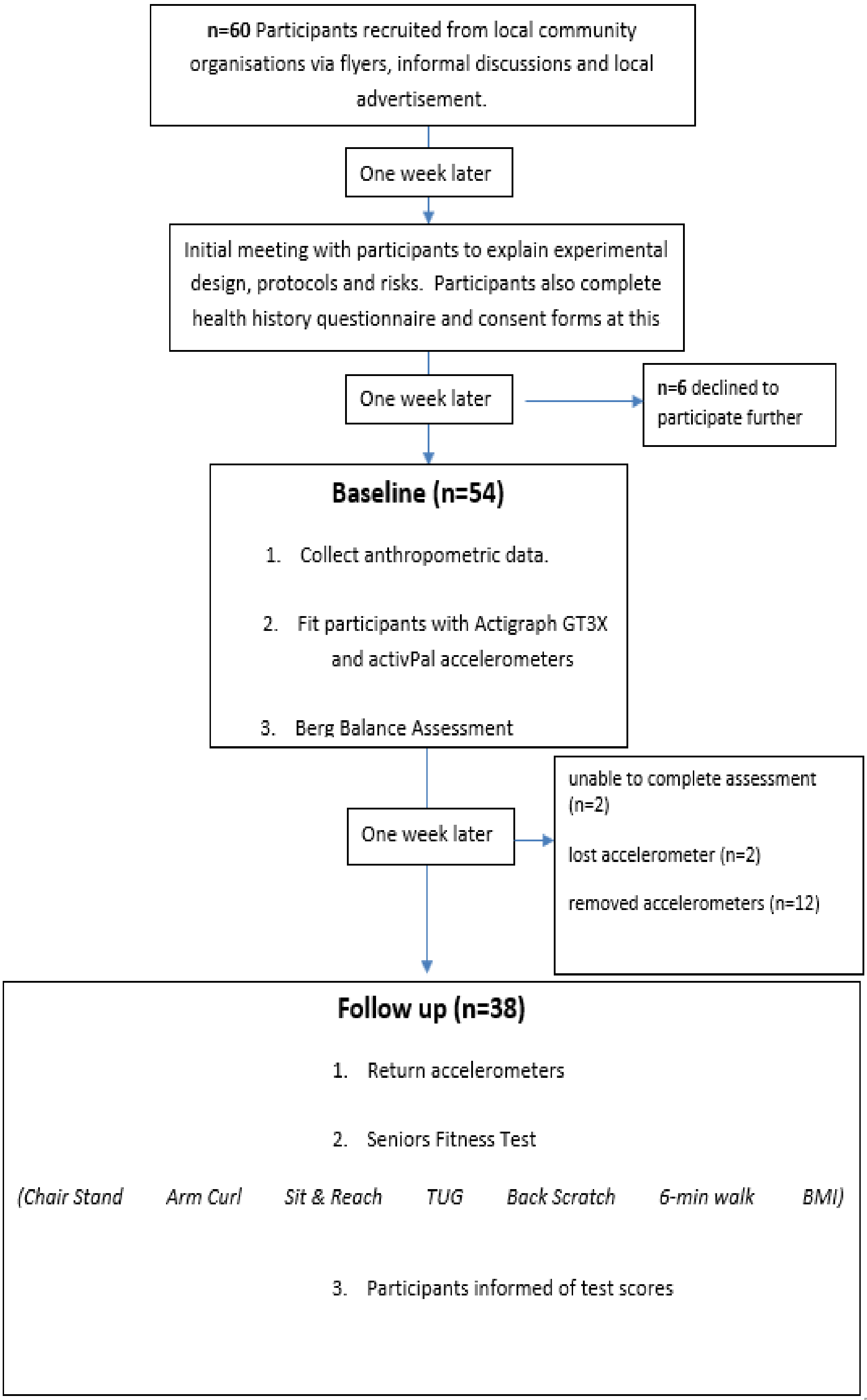


Figure 2.1 Flowchart for experimental procedures

2.3.3 Experimental Protocol

Prior to the assessments, participants were asked to:

- Avoid strenuous activity and excessive alcohol intake for at least 48 hours to ensure that metabolism was as close as possible to resting state before testing (Compher et al., 2006).
- Eat a light meal or snack one hour before testing.
- Wear appropriate clothing and footwear for participation in physical activity.
- Inform the administrator of any medical conditions or medications that could affect performance.

2.3.4 Baseline Measures

Initially, anthropometric measures (height and body mass) were determined using a free-standing stadiometer (Holtain Ltd, UK) and standard laboratory scales (Seca Delta, Germany). Participants then completed the Berg Balance Scale (BBS) assessment (appendix 7), which involved a series of fourteen low intensity physical tasks used to measure balance and monitor physical impairment in older adults in a clinical setting. The score for each task was recorded on a scale of 0-4 (higher scores indicated greater independent balance; low scores indicated a high risk of falling) with a maximum possible score of 56. According to Berg (1992) each point drop in the range 54-46 indicates a 6-8% increased risk of falls; each 1-point drop in the range 56-54 indicates a 3-4% increase in falls risk; a score of <45 indicates greater risk of falling (Berg, 1992). This assessment was chosen because it formed a common thread within research into physical impairment, frailty, falls risk and physical activity in elderly populations. Feedback on scores achieved was not made available at that time (so participants were blind to the implications of higher or lower scores during the forthcoming week of data collection). Participants were then fitted with two accelerometers; the Actigraph GT3X (Actigraph, Pensacola, USA), to measure PA, and the activPAL (PAL technologies, Scotland, UK), to measure SB (figures 2.3 & 2.3).

Figure 2.2 activPAL device attached to a participant's thigh (source: Edwardson et al., 2017)

Figure 2.3 Positioning of the Actigraph GT3x (source Rowlands & Stiles, 2012)

The Actigraph GT3x accelerometer (above) was used to record PA duration and intensity and was worn on an elastic belt over the right hip. Participants were instructed to wear the device for seven consecutive days, but to remove it each night before bed (except for water-based activities e.g. bathing or showering, where the device would also be removed). Wear time was determined by subtracting non-wear time from total daily observation time. Non-wear was defined as periods of at least 90 consecutive minutes of consecutive zeros, with an allowance of up to two consecutive minutes of counts between 1-100 (Heesh, 2018). A valid day was at least 10 hours of continuous wear. At least four days of wear (Hart et al., 2011) (including one weekend day) were required for inclusion in the analysis. Data from all three axes, using the low frequency extension (LFE), were used to indicate mean time per day spent in light (LIPA) PA (100-1951 cpm), moderate (MPA) PA (1952-5724 cpm), moderate to vigorous (MVPA) and vigorous (VPA) PA (5725-9498 cpm) (Freedson, 1998).

The activPAL was attached directly to the midline anterior aspect of the right thigh using adhesive hydrogel patch and medical grade adhesive patch (Hypafix, BSN medical). Participants were asked to wear the device continuously for a period of seven days, removing only for showering and bathing. This device was used to record sedentary time per day, total sitting/lying time per day and standing time per day, with at least four days required for data analysis (Edwardson et al., 2017) and data was processed using activPAL process and presentation v7.2.38. Compliance with wear time recommendations was confirmed using visual inspection of the individual data files. Sedentary time was calculated from individual data outputs using the technique developed by Chastin et al., (2014) where waking time was calculated as the first upright bout after ≥2hrs of continuous sitting/lying between 0.00 and 09.00 and ending with the last bout of standing before ≥3hrs of sitting/lying after 22.30.

Participants were provided with an information leaflet to assist with wearing the accelerometers over the coming week. After completion of the assessments, participants were asked to maintain their normal daily routine for the next seven days.

2.3.5 Follow-up Measures

Participants were asked to return the accelerometers one week later (Day 2), at which time they were assessed for functional fitness using the 'Seniors Fitness Test' (Rickli and Jones, 1999). This was a battery of seven tests including a chair stand, arm curl, body mass index, sit and reach, timed up-and-go, back scratch test and six-minute walk test. The test protocols for the 'Seniors Fitness Test' are outlined below:

1. **30-Second Chair Stand Test (to assess lower body strength)**

Participants were instructed to sit in the middle of the chair with back straight, feet flat on the floor, and arms crossed at the wrist and held against the chest. On the signal 'Go' the participant rose to a full stand, then returned to a fully seated position. The score recoded was the total number of stands that could be completed in 30 seconds.

2. **30-Second Arm Curl Test (to assess upper body strength)**

The participant sat on a chair with back straight and feet flat on the floor, with the dominant side of the body close to the edge of the seat. The weight (2.27kg/5lbs for women; 3.63kg/ 8lbs for men) was held down at the side, perpendicular to the floor, in the dominant hand with a handshake grip. From the down position, as the elbow bends the weight was curled up, with the palm gradually rotating to a facing up position during flexion of the elbow. The weight was returned as the elbow was fully extended down, with the hand returning to a handshake grip. The score was recorded as the total number of arm curls that could be completed in 30 seconds.

3. **Body Mass Index**

Height and body mass were determined using a free-standing stadiometer (Holtain Ltd, UK) and standard laboratory scales (Seca Delta, Germany). Height was recorded without shoes and body mass was recorded with minimal clothing. BMI = body mass (kg)/height (m^2).

4. **Chair Sit and Reach Test (to assess lower body flexibility)**

The participant sat on the edge of a 43cm chair. The crease between the top of the leg and the buttocks was even with the front edge of the chair seat. One leg was bent and slightly off to one side with the foot flat on the floor. The other leg was extended as straight as possible in front of the hip. The heel was placed on the floor with foot flexed at approximately 90^0. With arms outstretched and overlapping and middle fingers even, the participant slowly bent forward at the hip joint as far as possible toward or past the toes. If the extended knee started to bend, the participant was asked to move slowly back until the knee was straight. The maximum reach was held for 2 seconds. The score was the measured distance (cm) remaining from the tips of the middle fingers to the toe end of the shoe.

5. **Back Scratch Test (to assess upper body flexibility)**

Participants stood and placed the preferred hand over the same shoulder, palm down and fingers extended, reaching down the back as far as possible. The other arm came around the back of the waist, palm up, reaching up the middle of the back as far as possible in an attempt to touch or overlap the middle fingers of both hands. The score was the measured distance (in cm) between the tips of the middle fingers.

6. **8 ft (2.45m) Up and Go Test (to assess agility and dynamic balance)**

The participant was instructed to sit in the middle of the chair with back straight, feet flat on the floor and hands on the thighs. One foot was positioned slightly in front of the other, with the torso slightly leaning forward. On the signal 'Go', the participant rose from the chair, walked as quickly as possible around the cone (placed 2.44m away) and back to sit down again. The score was the time taken to complete the walk from start to finish.

7. **The 6-Minute Walk Test (to assess aerobic endurance)**

Participants were instructed to walk around a flat rectangular indoor course for 6 minutes as quickly as possible. The score was the total distance travelled in the 6-minute period.

The course was a 50m rectangle (20m x 5m) marked off in 5m segments, located in an indoor sports hall, with a flat, non-slip walking surface. Multiple participants were assessed at one time, with the starting times of individual participants staggered by ten seconds to encourage individual pacing. Participants were given a marker for each lap completed and were instructed to stop when the 6-minute time period had elapsed. An oral time check was provided at the 3-minute mark and the 2-minute mark, and administrators provided gentle verbal encouragement throughout the test. Participants were permitted to stop and rest, at any time, on chairs provided at 5m markers around the course but the testing time continued to run. Water was made available to drink ad libitum. At the end of the test participants were instructed to continue to walk slowly to cool down after which they were accompanied to stretch the lower leg area. Participants were permitted to adjust their pace up or down or stop at any time during the test.

2.3.6 Statistical Techniques

All statistical analyses were performed using SPSS V.23.0 (SPSS Inc, Chicago, Illinois, USA). Results are presented as means and standard deviations for continuous data (individual test results, height, body mass, age), and numbers and percentages for categorical data (gender). Histograms and stem and leaf plots were used to examine normality of distribution of continuous variables. Initially, a bivariate analysis was conducted using a correlation matrix to determine the association between the predictor and outcome variables; this was quantified using Pearson's r and p values. This was followed by multiple (hierarchical) regression models which were used to determine which variable or combination of predictor variables were more closely associated with physical impairment. Models were analysed using R^2 (variance explained adjusted for number of predictors in the model) and unstandardized beta coefficients (changes in the outcome per unit change in the predictor variables). Using a hierarchical approach, the changes in R^2 were also examined between model 1 (sedentary behaviour) and model 2 (physical activity and sedentary behaviour).

2.4 Results

2.4.1 Participant Demographics

Thirty-five females (65% of total) and nineteen males (35% of total) participated in this study. Participant demographics are reported in Table 2.1.

Table 2.1 Participant characteristics presented as mean (SD)

Participants	Age (yrs)	Height (m)	Body Mass (kg)	Body Mass Index (kg.m^{-2})
(n=54)	73.5 (2.35)	1.65 (10.7)	70.6 (10.7)	25.87 (3.06)

2.4.2 Seniors Fitness Test (SFT) and Berg Balance Scale

Jones & Rikli (2002) published normative values for the SFT, to be used as a guideline for practitioners. Table 2.2 (below) provides a summary of the scores achieved by participants along with a comparative value for each score, described by Jones and Rikli (2002) as 'normal range' (i.e the middle 50% of the population). Participants scoring above the normal range were considered above average for their age in that particular functional fitness characteristic, while those scoring below the range were considered below average. Table 2.2 indicates that participants recorded mean test scores within the 'normal' age-related range of ability (Jones & Rikli, 2002) in all but two of the measures of functional fitness; the Back-Scratch test and the 8ft Up&Go. Male participants performed better than female participants in all elements of the SFT apart from the back scratch test.

Table 2.2 Seniors fitness test scores; mean (SD) and normal (70-80 yrs) range (source: Rickli & Jones, 2002)

(n=54)	Male	Female	All
Chair Stand (reps.30s^{-1})	12.8 (3.2)	11.9 (3.3)	11.5(3.1)
Normal Range	11-17	10-17	10-17
Arm Curl (reps.30s^{-1})	13.3 (2.9)	12.7 (3.8)	12.9 (3.0)
Normal Range	14-19	12-17	12-19
Sit and Reach (cm)	+1.4 (5.6)	+3.5 (7.2)	+3.9 (7.2)
Normal Range	-3.5 to +2.5	-1.4 to +4.0	-3.5 to 4.0
Back Scratch (cm)	+15.1 (8.7)	+11.7 (10.2)	+12.6 (10.6)
Normal Range	-9 to -1	-4 to +1.0	-9 to +1.0
8ft Up & Go (s)	7.5 (2.2)	8.2 (3.2)	8.2 (2.5)
Normal Range	7.2 - 4.2	7.4 - 4.9	6.2 – 4.6
6-Min Walk (m)	503.3 (87.7)	445.9 (127.5)	439.7 (123.4)
Normal Range	470 - 680	430 - 615	430 - 680

There was little difference in the Berg Balance scores achieved by male versus female participants, though females demonstrated a greater range of scores than their male counterparts. The maximum attainable score in this assessment was 56 and 35% of participants achieved this score. A summary table of BBS scores for all participants is presented in Table 2.3.

Table 2.3 Berg Balance Scale results for all participants (with SD and range)

	Mean	SD	Min.	Max.
All (n=54)	51.4	7.2	14	56

2.4.3 Objectively Measured Physical Activity and Sedentary Behaviour

Mean wear period for the Actigraph was seven days (range 6-7) with a mean wear time of 12.2 hrs.day^{-1} (SD 7.2). Mean wear period for the activPAL was seven days (range 6-7) on a continuous wear protocol. Accelerometer data and reported mean daily figures were adjusted to account for individual wear periods and are presented below in Table 2.4. The

Actigraph was used to record LIPA, MVPA, total PA and total steps. The activPal was used to record total sit/lie/sleep, sedentary time and standing time. In addition to the data presented for sedentary time, the results presented here also include data for total time spent sitting/ lying/ sleeping, which adds time spent sleeping (participants wore the activPal using a continuous, 24hr protocol) to the sedentary periods.

Table 2.4 Actigraph and activPAL scores (SD) for physical activity, SB and sit/lie/sleep time

(n=38)	Male	Female	All
LIPA (min.day^{-1})	300.9 (60.7)	288.3 (75.1)	287.0 (67.3)
MVPA (min.day^{-1})	28.2 (27.5)	25.6 (26.7)	24.1 (24.8)
Total PA (min.day^{-1})	328.1 (71.8)	313.9 (89.5)	311.7 (75.2)
Total Steps.day^{-1}	8041.7 (51210.6)	10980.5 (5043.4)	9745.3 (4879.5)
Total sit/lie/sleep (hr.day^{-1})	18.4 (1.5)	18.3 (1.9)	18.3 (1.7)
Sedentary time (hr.day^{-1})	9.6 (1.4)	9.3 (1.7)	9.5 (1.5)
Standing time (hrs.day^{-1})	4.3 (1.4)	4.5 (1.0)	4.4 (1.2)

2.4.4 Bivariate Correlations

An exploratory bivariate correlation matrix was drawn between measures of physical activity/ sedentary behaviour and measures of physical function. Results are shown in Table 2.5

Table 2.5 Bivariate correlation matrix

		LIPA (min.d^{-1})	MVPA (min.d^{-1})	Total PA (min.d^{-1})	Total Steps.d^{-1}	Total Sit/Lie /sleep (hr.d^{-1})	Total Sed. (hr.d^{-1})	Total Stand (min.d^{-1})
BMI	*r*	-.027	-.216	-.088	-.102	.381*	.434**	.335*
	p	.855	.133	.543	.481	.020	.006	.040
Chair Stand	*r*	.451**	.338*	.495**	.501**	.503**	-.129	-.051
	p	.001	.018	.000	.000	.000	.439	.762
Arm Curl	*r*	.136	.263	.205	.074	-.230	-.137	.079
	p	.356	.067	.159	.611	.170	.412	.638
Sit & Reach	*r*	-.057	-.080	-.072	.035	.362*	.210	-.250
	p	.702	.583	.621	.809	.028	.205	.131
Back Scratch	*r*	-.140	.129	-.062	.269	.224	.207	.067
	p	.342	.376	.670	.061	.182	.211	.689
Up & Go	*r*	-.275	-.259	-.316*	-.090	.430**	.052	.299
	p	.058	.073	.027	.539	.008	.758	.068
6-min Walk	*r*	.108	.327*	.208	.200	-.346*	-.246	.082
	p	.474	.027	.166	.182	.039	.142	.630
Berg Balance	*r*	.267	.187	.296*	.223	-.477**	-.282	.138
	p	.063	.194	.037	.119	.003	.086	.407

Correlations between measures of sedentary time/ physical activity and measures of physical function. * *denotes significance at p≤.05 (2 tailed),* ** *denotes significance at p≤.01 (2 tailed).*

Both PA and SB demonstrated an association with measures of physical impairment for the assessments used in this study. Only BMI showed a significant correlation (r>0.25) with SB but six measures of physical function demonstrated at least a moderate correlation (r>0.25) with total time spent sitting/lying/sleeping (an extension of sedentary time).

Correlations between predictor and outcome variables at, or above r = 0.25 (p≤0.01) were then included in the single regression models to examine the magnitude and direction of the relationship between individual measures of physical impairment. R^2 values, unstandardized and standardised beta values are shown in Table 2.6 for each relationship

Table 2.6 A table showing R^2 values for regression analysis

	LIPA	MVPA	Total PA/day	Total sit.lie/sleep/ day	Total Sed.	Total Stand/day
BMI	.14 (.76,.38)		.01 (-.004,.01)	.14* (.76,.38)	.19** (0.99,.43)	.11* (.97,.33)
Chair Stand	.20** (.02,.45)	.11* (.04,.34)	.24** (.02,.49)	.03 (-.34,.20)		
Sit & Reach				.13* (1.3,.36)		
Up & Go			.10* (-.01, -.32)	.19** (.68, .43)		
6-min Walk		.33* (1.6,.33)		.12* (-22.25,-.35)		
Berg Balance			.09* (.03, .30)	.23* (-2.02, -.48)		

R^2(unstandardized β, standardised β) for dependent/independent variables showing bivariate relationships with Pearson's correlation coefficients recorded at r ≥ 0.25(p≤0.01). Note ** denotes significance at .01 level (2 tailed), * denotes significance at .05 level (2 tailed).

2.4.5 Sedentary Time and Physical Impairment

A moderate correlation was found between sedentary time per day and BMI (figure 2.4). The R^2 was .19 indicating that a change to sedentary time was associated with 19% of the difference in BMI. The unstandardised β coefficient was .99, meaning that an additional 1kg.m^{-2} BMI was associated with an increase of 59.4 min.day^{-1} of sedentary time. Given that the mean sedentary time for participants was recorded at 9 hr 29 min.day^{-1}, with a mean total sitting/ lying/ sleeping time of 17 hr 57.6 min.day^{-1}, this score may have some clinical relevance for health beyond that of physical impairment alone.

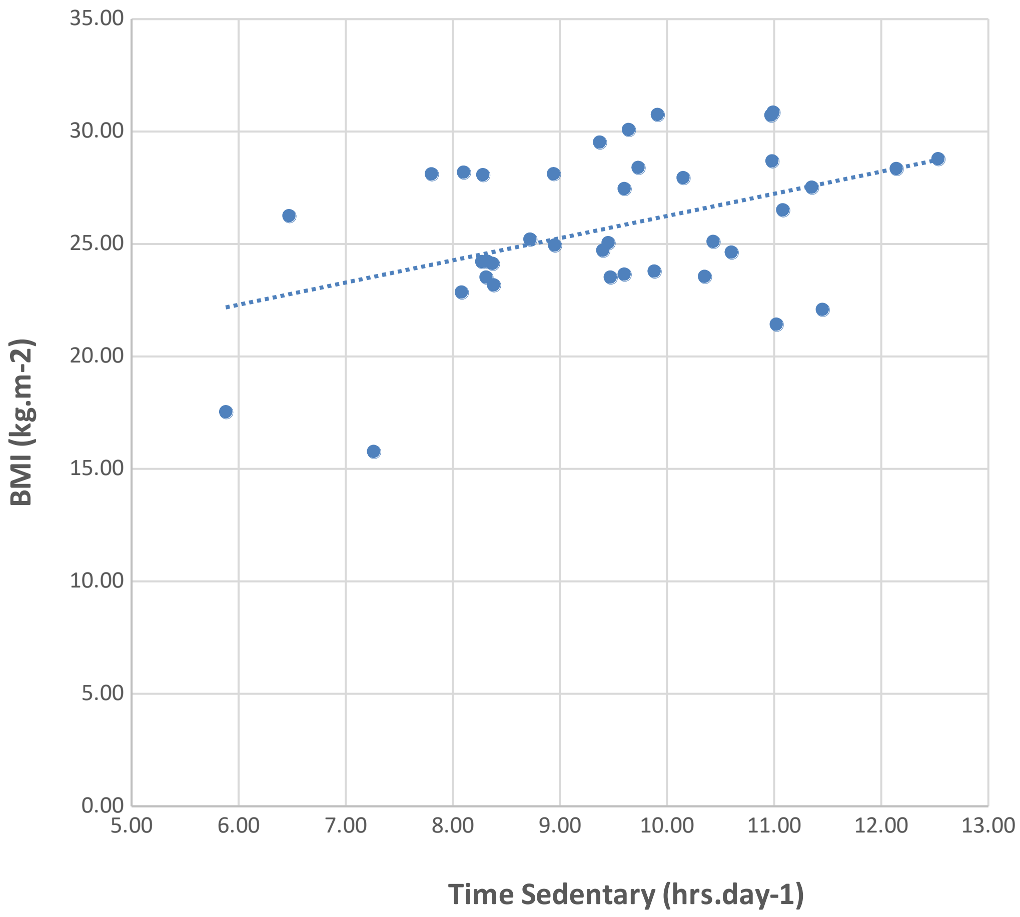


Figure 2.4 Relationship between BMI and total sedentary time per day

Although sedentary time was not associated with any other measure of physical impairment, total time spent sitting/ lying/sleeping was associated (P≤0.05) with five separate physical impairment variables: BMI (R^2=.14, β =.76); sit and reach (R^2=.13, β =1.3); Up and Go (R^2= .19, β =.68); 6-min walk (R^2=.12, β =-22.25) and the Berg Balance assessment (R^2=.21, β =-2.02), suggesting that total time spent sitting/ lying/ sleeping had a more consistent association with physical function than sedentary time. Unstandardised β coefficients suggested that a 30 min.day^{-1} total reduction in sitting/lying/sleeping were associated with an additional point in the Berg Balance assessment, though no such relationship was found between sedentary time and Berg Balance. Time spent standing was also independently associated with BMI (R^2=.11, β .97).

2.4.6 Physical Activity and Physical Impairment.

The strongest association here (figure 2.5) was between Total PA.day^{-1} and the Chair Stand test (R^2=.24, β .021 p≤0.01). MVPA and LIPA were also associated with the Chair Stand (R^2 values of .11 and .20 (p≤0.05) respectively). The unstandardized β values for these relationships indicated that each additional repetition in the chair stand test was associated with higher total PA of 47.6 min.day^{-1} or 23.2 min.day^{-1} of MVPA.

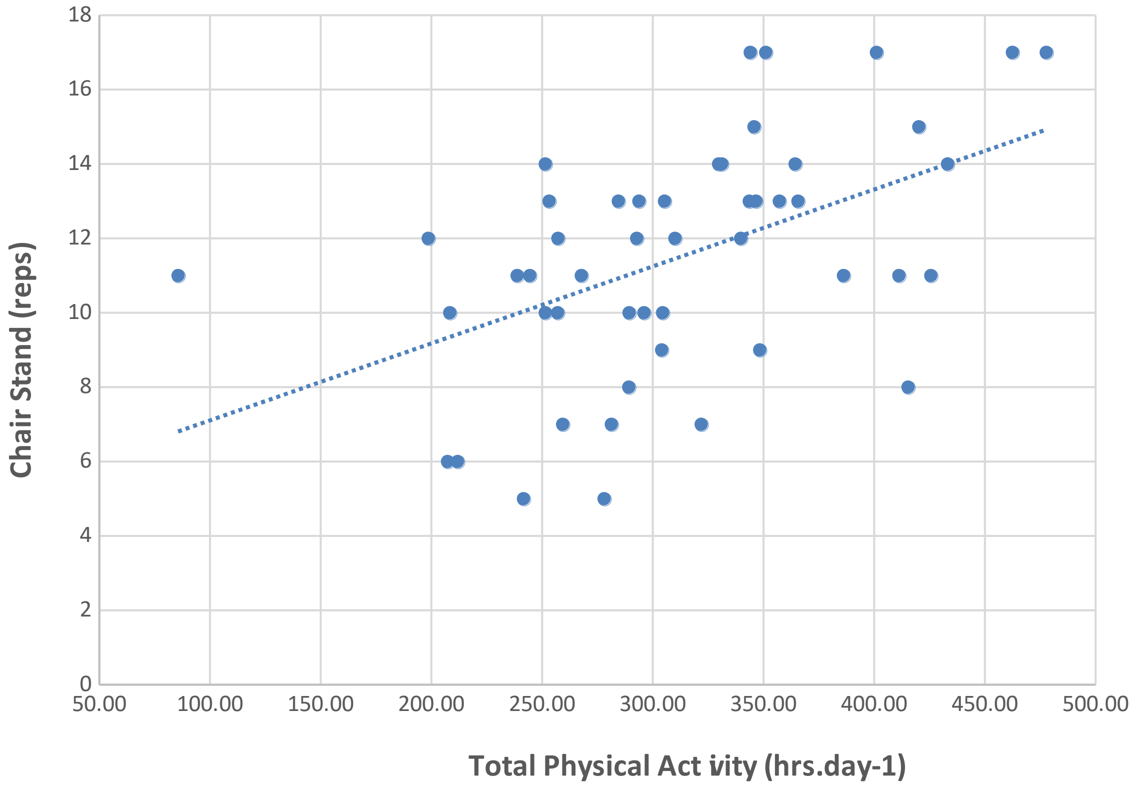


Figure 2.5 Relationship between chair stand repetitions and total PA per day

Total PA per day was also moderately associated with the 8ft Up&Go test (R^2=-.1, β -.01, p≤0.05), indicating that an additional 90 min.day^{-1} total PA was associated with an improved score of 1s in the 8 ft Up&Go. The unstandardised β coefficient of .03 indicated that 34.5 min.day^{-1} of total PA was linked to an improvement of one point on the Berg Balance scale (R^2=.09). The mean score achieved in this test was 51.4 out of a possible 56 points. Given that the mean total PA achieved by participants was 5 hrs, 12 min.day^{-1}, an extra point on this test was associated with 11% higher total PA.

MVPA was independently associated with the 6-min walk (R^2 .33, β 1.59), meaning that an additional 6.3 min.day^{-1} of MVPA was associated with an additional 10 m in the 6-min walk test. (the mean distance achieved by participants in this test was 439.7m). The mean MVPA score achieved by participants was 24.1 min.day^{-1} so it could be hypothesised that an individual would need to increase their MVPA by 25% (to 30.4 min.day^{-1}) to achieve ten additional metres in this test. Table 2.7 (below) shows the amount of additional physical activity or reduced sedentary time required for a given change in the individual outcome variables. The figures presented here suggest that a 90 min.day^{-1} reduction in total sitting/ lying time was associated with more areas of physical function than any other predictor variable. If this was accompanied by, an increase of 48 min.day^{-1} of total PA, every outcome variable measured in this study would see a positive change.

Table 2.7 Table showing the impact of a given change in predictor variables on outcome variables

Change required / Outcome	Increased Duration Total PA (min.day^{-1})	Increased Duration MVPA (min.day^{-1})	Reduced Total Sit/Lie/sleep Duration (min.day^{-1})	Reduced SB Duration (min.day^{-1})	Increased Standing Duration (min.day^{-1})
BMI (-1kg.m^{-2})			91	59.4	61.2
Chair Stand (+1 rep)	47.6	23.2			
Sit and Reach (+1cm)			45		
8 ft Up&Go (-1 second)	90		88.2		
6-Min Walk +10m		6.3	26.9		
Berg Balance Scale (+1 point)	34.5		30		

2.4.7 Multiple Regression Analysis

A hierarchical multiple regression analysis was conducted to examine whether SB or total sit/lie/sleep, together with PA (SB or sit/lie/sleep entered into the model first) would together add strength to the regression model, particularly in the relationships where both PA and SB or sit/lie/sleep were separately correlated with physical function. Total sedentary time accounted for 23.3% of the variation in BMI and this was significant ($p<.01$). The addition of PA to the model did not result in any additional change. Total time spent sit/lie/sleep accounted for 9.3% of variation in the Up&Go test. The addition of PA explained an additional 7.2% of the variation but this change was not statistically significant ($p>.05$). Total time spent in sit/lie/ sleep accounted for 7.7% of variation in the Berg Balance Scale. The addition of PA explained an additional 6.5% of the variation but once again, this change was not statistically significant ($p>.05$). The multiple regression analysis provided no additional statistical strength to the associations already established in the single regression analysis between predictor and outcome variables. Table 2.8 provides a summary of the results.

Table 2.8 Summary table of hierarchical regression analysis

	(Total Sedentary Time or Sit/Lie/Sleep) and Total PA				
	R^2	R^2 Change	Unstandardised β	Standardised β	p
Body Mass Index					
Model 1	.28	N/A			
Total sedentary time			0.18	.52	.001
Model 2	.28	0			
Total sedentary time			.18	.52	.002
Total PA			-.001	.02	.89
8ft Up and Go					
Model 1	.07	N/A			
Total sit.lie.sleep			.07	.27	.11
Model 2	.11	.04			
Total sit.lie.sleep			.06	.21	.24
Total PA			-.01	-.20	.25
Berg Balance Scale					
Model 1	.08	N/A			
Total sit.lie.sleep			-.20	-.27	.10
Model 2	.14	.06			
Total sit.lie.sleep			-.14	-.18	.29
Total PA			.02	.27	.12

Analysis performed with independent variables (total time sitting/ lying/ sleeping, total sedentary time, total physical activity) predicting physical impairment (body mass index, 8ft up & go, Berg Balance Scale

2.5 Discussion

This cross-sectional study aimed to investigate whether SB, independent of PA, was associated with physical impairment in a sample of independent, community dwelling older adults. Results showed that, overall, PA was a better predictor of physical impairment than SB because it was associated ($r \geq 0.25$, $p \leq 0.05$) more often with the functional and clinical indicators of physical impairment used here. However, total time spent sitting/lying/sleeping was also independently associated with measures of physical impairment. The findings from this study indicate that:

a. SB did not independently predict physical impairment in this group of older adults.
b. Both total sit/lie/sleep time and total PA predicted physical impairment in this population.
c. Total time spent in sit/lie/sleep was a better indicator of physical impairment than SB.
d. The addition of PA to sit/lie/sleep variables in a hierarchical regression analysis did not improve the predictive ability of the model.

High SB and low PA have been associated with negative health outcomes including an increased risk of cardiovascular and metabolic diseases, cancer, obesity and diabetes (Giné-Garriga et al., 2017; Ekelund et al., 2019). Participants in this study were found to be sedentary 9.5 $hrs.day^{-1}$ with a total sitting/ lying time of 18.3 $hrs.day^{-1}$. Males and females recorded almost identical SB (9.6 $hrs.day^{-1}$ vs 9.3 $hrs.day^{-1}$) and total sitting/lying/ sleeping time (18.4 $hrs.day^{-1}$ vs 18.3 $hrs.day^{-1}$). This tallied with the literature where median time spent in SB and in sitting/lying/sleeping for older adults were found to be 9.4 $hrs.day^{-1}$ and 18.06 $hrs.day^{-1}$ respectively (Genusso et al.,2016; Fitzsimons et al. 2013). Harvey et al. (2015) found that SB among older adults increased with advancing age and reported that people aged over 60 spent 60-80% of their waking day sedentary. In the current study, approximately 60% of participants' waking day was spent sedentary.

PA levels here were broadly similar to other studies, with participants recording a mean of 9745 steps.day^{-1}. Males recorded 10.1% more MVPA per day than females but only 4.5% more total PA per day. Ekelund et al., (2019) reported the mean value for total PA among US men as 10-15% higher than in US women, depending on age. Levels of MVPA in the present study were 168.7 min.wk^{-1}, exceeding the internationally recommended dose of 150 min.wk^{-1}.

SB has been reported to diminish physical function in older adults (Gennuso et al., 2013). However, in a 2016 study by the same author, some of the physical function assessments (handgrip strength, postural stability and fall risk) lacked a statistically significant relationship with SB (using the Short Physical Performance Battery (SPPB). The authors found evidence suggesting a negative association between longer bouts and fewer breaks in SB and reduced physical function but reported a 'ceiling effect' of testing due to the high functional ability of the sample. Langley et al., (2007) also reported a ceiling effect when using the BBS to assess static balance with community dwelling older adults and suggested the use of dynamic balance assessments with this cohort. A ceiling effect may have occurred in the present study, where participants were independent community dwellers who met or exceeded 'normal' scores in both the SFT and Berg Balance Scale (BBS), and who's median MVPA level exceeded internationally recommended population guidelines. For example, 35% of participants in the current study achieved the highest possible score in the BBS.

The measurement of SB among older adults can be problematic. The current definition limits the reporting of SB to waking hours. This complicates the SB measurement process with older adults who can experience polycyclic sleeping patterns (Winkler et al., 2016). Some older adults supplement their sleep at various times during the day and the postural inclinometer in the activPAL may wrongly identify this behaviour as sedentary. Alternatively, older adults may go to bed in the evening (or remain in bed in the morning) to read, watch television or to keep warm, which could be wrongly identified as sleeping time by the activPAL. Ways around this problem include the use of sleep and activity diaries (which improve accuracy, but which add to participant burden and can sometimes be unreliable due to recall), or the more recent use of machine learning or automated algorithms (Winkler et al., 2016). Therefore, the method chosen to calculate SB in this study (Chastin et al., 2014) may have influenced the results. In this case, waking time was calculated as the first upright bout after ≥2hrs of continuous sitting/lying between 0.00 and 09.00 and ending with the last bout of standing before ≥3hrs of sitting/lying after 22.30. However, this method could not account for non-nocturnal sleeping patterns or for sitting/lying down while awake during the night or in the morning. Consequently, the relationship between physical function and total 24 hr time spent sitting, lying and sleeping was also examined. Replacement of SB with equal amounts of standing and sleeping (using isotemporal substitution models) has previously been linked with mortality risk reductions in middle age and older adults defined as low sleepers (Stamatakis, 2015).

In this study, although SB was only associated with one measure of physical impairment, total time spent sitting/lying/sleeping was associated with five elements. This may not be surprising given that sitting/lying/sleeping is an extension of SB, involving an identical posture and continued low energy expenditure. Very low energy expenditure is the functional antithesis of both MVPA and force production, and it is unsurprising that total sitting/lying/sleeping time was negatively associated with the 8ft Up&Go test (requiring explosive muscular force), the 6-min walk test (requiring both aerobic and muscular endurance) and the Berg Balance Scale (requiring the use of muscular force and motor control in an upright position).

The physical impairment that is associated with SB may become more apparent below a functional threshold level, given that the participants in this study were already within the 'normal' range of physical function. Alternatively, SB may be associated with more discreet physiological changes than those assessed by the SFT and Berg Balance Scale e.g. blood lipids, insulin, cholesterol, BMI (Wirth et al., 2017). Indeed Liu et al. (2019) found no significant correlation between BMI and other elements of functional fitness (using the SFT) in a sample of 845 adults aged over 65 years. Evidence for a possible health-related association between SB and BMI is provided in this study with an increase of $1kg.m^{-2}$ for every hour of additional SB experienced by participants. Ballegooijen et al., (2019) found a strong correlation between high SB/ low PA and BMI among 1201 older adults in the Netherlands. Jefferis et al., (2016) found that each additional 30 $min.day^{-1}$ of SB was associated with 0.32 $kg.m^{-2}$ higher BMI. However, they also found that every additional 30 $min.day^{-1}$ of MVPA was associated with -0.72 $kg.m^{-2}$ BMI, a finding that was not replicated in this study.

High BMI scores have been associated with increased incidence of metabolic syndrome, type II diabetes and cardiovascular disease (Wirth et al., 2017; Copeland et al., 2017) among older adults and studies have found associations between time spent sedentary and risk of death

(Matthews et al., 2016), indicating a harmful link between SB and health. Older adults in the NHANES study (Matthews, 2016) who spent 10 hours per day sedentary had a 29% greater risk of death than those who spent under 6 hours per day sedentary. Replacing 1hr of SB with either light or moderate PA was associated with 18% and 42% lower mortality respectively, suggesting that increasing even light PA could be an effective strategy to reduce mortality in this population. Ekelund et al., (2019) also reported substantial mortality risk reductions from light intensity physical activity in a dose-response fashion, suggesting that increased total PA and SB reduction could be as effective in reducing mortality risk in older adults as increases in daily MVPA. The importance of SB reduction or increased light, or total, PA could be an important consideration for older adults. McGowan et al., (2016) suggest that older people may not see physical activity as a relevant, separate, purposeful construct and are more likely to engage in PA as a by-product of other activities. Consequently, the authors advise that interventions should be aimed at reducing sedentary behaviour rather than specifically increasing PA in this population.

2.6 Limitations of this study

Many of the cross-sectional studies in literature that examine PA or SB in conjunction with physical function do so with large sample sizes (>500). The sample used in this study was only large enough to attain statistical significance ($p \leq 0.05$) for a moderate correlation coefficient of ~$r = 0.25$ and may have missed the strength of association that could be associated with a larger sample size (potential for Type II error).

Although the study was intended to include participants from across the functional spectrum and equally across both sexes, random sampling of the population was not possible, so participants were volunteers drawn from community and church groups. Participants were also more likely to be female, highly functional and were more active than the 'average' older adult aged ≥70 yrs. Therefore, the functional status of participants at baseline and volunteer bias may need to be considered in the generalisability of the findings.

The Berg Balance Scale is an assessment where participants perform a series of fourteen low intensity physical tasks used to measure balance and monitor physical impairment in older adults in a clinical setting. The score for each task was recorded on a scale of 0-4 (higher scores indicated greater independent balance; low scores indicated a high risk of falling) with a maximum score of 56. 35% of participants scored maximum points on almost all elements of the assessment, suggesting that a ceiling effect may have been observed and functional balance may not have been fully assessed in some individuals. A more challenging assessment such as the Fullerton Advanced Balance Scale (Rose et al., 2006) may have been more appropriate for this group and may have been more sensitive to smaller changes in postural balance.

Time spent in SB is difficult to quantify using objective measurements alone, without direct observation. This is particularly the case with older, retired adults, who tend to have less structured daily schedules than their younger counterparts. Therefore, a combination of subjective and objective (via log entries) SB measurement may have provided context for the data provided by the body-worn monitors.

Seasonal and Environmental Influences on PA and SB – Physical activity levels may be sensitive to changes in season and weather conditions for older adults, more so than the general population (Hagströmer et al., 2014). Fear of injury or falls, poor visibility, shorter days and colder weather may change the daily habits of participants. Therefore, objective measurement of PA/SB using accelerometers that are worn for one week, may not provide an accurate view of typical habitual activity in this cohort.

Finally, the results need to be placed in context of the study design. This was a cross-sectional examination of the relationship between PA, SB and physical function and used a large number of outcome variables. Although associations were reported between predictor and outcome variables, these relationships should not be regarded as cause and effect and many other factors could influence the changes in physical impairment beyond the predictors used in the current study. The study was exploratory but provided potential avenues for further study.

2.7 Conclusions

Hypokinetic diseases among older adults have been associated with mobility disability (including increased falls risk), cognitive decline, social isolation and depression (Leask et al., 2015; Copeland et al., 2017). Recently, evidence has demonstrated a link between SB and adverse health incomes, independent of PA (Santos et al., 2012; Ekelund et al., 2016; Jefferis et al., 2016). Older adults are the most sedentary and least physically active section of the population and may benefit from the protective effect of a combined increase in PA and reduced SB. Although physical activity guidelines tend to concentrate on daily and weekly doses of MVPA, the results of this study suggest that total PA (light, moderate and vigorous

PA combined) and total time spent sitting/lying are also useful indicators of overall physical functional status for older adults. In this study, total sitting/lying time and total PA were found to be separate, yet significant correlates of most elements of physical impairment in a group of older adults age 70-79. There was a moderate correlation between SB and BMI, though SB was not associated with any other element of physical function. This suggests that if SB is related to physical function, it may be associated with more discreet metabolic or physiological indicators that were not examined in this study. Also, the participants here were a high functioning group of older adults so the law of diminishing returns may have applied to the functional assessments. Associations within a group of adults with lower levels of physical function may have been greater.

Chapter 3

Systematic Review

The Effectiveness of Physical Activity and Sedentary Behaviour Interventions in Altering Sedentary Behaviour Among Older Adults: A Systematic Review.

The findings of the review were published as an abstract in Lancet and were presented at the Public Health Conference held in Belfast in November 2018.

3 Chapter 3

3.1 Introduction

Long and frequent bouts of sedentary behaviour (SB) pose a significant risk to health and increase the incidence of hypokinetic diseases (Gennuso, 2013; Tremblay et al., 2010) and mortality (de Rezende et al., 2014). Older adults are reported to be the least physically active members of the population and those aged over 65 currently account for 30-40% of European healthcare costs (Giné-Garriga et al., 2017).

Recent reviews investigating SB among older adults have primarily focused on associations between health outcomes and the prevalence and incidence of SB. Older adults spend around 9.4 hours per day sedentary, equating to 65–80% of waking hours (Harvey et al., 2015), though bouts of SB differ in number and duration (Kang & Rowe, 2015). Environmental factors and advancing age are independently linked with higher levels of SB among older adults (Chastin et al., 2015) and there may be an association between SB and cardiovascular and metabolic biomarkers in this cohort (Wirth et al., 2016).

Interventions aimed at reducing sedentarism among older adults (Fitzsimons et al., 2013; White et al., 2017) are still scarce but those involving behaviour change (Fitzsimons, 2013; Gardiner et al., 2016) and those seeking to reduce the number of sedentary bouts per day, have shown promise (Wullems et al., 2016). However, a systematic review examining the quality or effectiveness of intervention trials seeking to modify sedentary behaviour among older people has not yet been published.

The aims of this review were to synthesise the current evidence on SB interventions among adults aged over 60 and to assess the potential clinical impact of both PA and SB interventions where a change in sedentary behaviour was a main outcome measure. This information could be used to direct the focus of future intervention studies.

3.2 Methods

3.2.1 Search Strategy

In May 2017, the following databases were searched in conjunction with a subject specialist librarian: Cumulative Index of Nursing and Allied Health Literature (CINAHL); MEDLINE (Ovid); Exerpta Medica (EMBASE); PROQUEST (Health and Medical Collection); Sedentary Behaviour Research Network (SBRN) database. A BOOLEAN search strategy was employed, which combined MeSH terms and keywords related to three main areas: sedentary behaviours; physical activity; older adults. Where MeSH terms were used, all sub-headings within the MeSH term were included in the search and relevant terms were exploded to reveal additional terms of reference. The initial search was conducted by MMc and replicated by MRH. A manual search was also conducted of the SBRN database and of the reference lists associated with any full papers screened. MEDLINE search results are presented in figure 3.1. In the initial search, one reviewer (MMc) screened articles based on titles and abstracts. All titles chosen for full paper review were retrieved and assessed for eligibility by one reviewer and checked by a second reviewer (MM). Any disagreements were mediated by a third reviewer (CB). Twelve studies met the criteria and were selected for inclusion.

1	Sedentary Lifestyle/
2	sitting.mp.
3	inactivity.mp.
4	screen time.mp.
5	screentime.mp.
6	computer time.mp.
7	Television/
8	television.mp.
9	sedentary.mp.
10	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9
11	Motor Activity/
12	physical activit*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier]
13	exp Exercise/
14	exercis*.mp.
15	"Activities of Daily Living"/
16	ADL.mp.
17	Activities of daily living.mp.
18	Postural Balance/
19	postural balance.mp.
20	11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19
21	Aged/
22	old.mp.
23	old age.mp.
24	older.mp.
25	"older adult".mp.
26	elderly.mp.
27	senior.mp.
28	aged.mp.
29	Middle Aged/
30	"middle aged".mp.
31	21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30
32	10 and 20 and 31
33	limit 32 to (english language and humans)

Figure 3.1 Search strategy used in MEDLINE and EMBASE

3.2.2 Inclusion and Exclusion Criteria:

Intervention studies published in English, using human participants aged 60 years and over, that reported a subjective or objective measurement of PA or SB, were included. One of the reported outcomes needed to be a change in sedentary time (e.g. sitting time, lying or reclining time, screen time, television watching). There were no restrictions on disease characteristics of participants, types of intervention used, the nature of the comparison group or year of publication. Publications were included up to 31st May 2017. Studies were excluded if participants were under 60 years old. Intervention studies that did not have an outcome related to sedentary behaviour (SBRN, 2012) were also excluded.

3.2.3 Data Extraction and Quality Assessment

The data were extracted by one researcher (MMc) and reviewed by three other researchers (MM, CB and JM). A standardised template of headings was used to extract study designs, participant characteristics and outcomes (appendix 11). The quality assessment was conducted independently by two researchers (MMc and CB) and any discrepancies were mediated by a third and fourth researcher (MM and JM) at two consensus meetings. The quality assessment tool used was the Cochrane Collaboration's Tool for assessing Risk of Bias (ROB), using the guidelines provided by Higgins et al. (2019). This assessment tool addresses six domains of potential bias within a study: selection bias, performance bias, detection bias, attrition bias, reporting bias and 'other' bias. Higher quality studies were considered to include a control group, objectively derived outcomes and fewer baseline imbalances so 'other' bias in this case was divided into 'control group', 'subjective measures' and 'baseline imbalances'. Each potential source of bias within the study is supported by a judgement by the researcher and is presented with a risk score (low, unclear or high ROB). In accordance with Overall risk of bias was assessed in the same manner as the individual domains. For example, a high risk of bias in any domain was determined to have the same implication for the overall result, regardless of the domain in question. The full ROB table including final judgements is included in Appendix 12 Table 3.1 shows the methodological quality of domains within all studies included in the review.

3.2.4 Data Analysis

Due to a high level of heterogeneity in study designs and outcomes, a meta-analysis of effect estimates for the included studies was not possible. Instead, a narrative synthesis was conducted in accordance with SWiM guidelines (Campbell et al., 2020). Initially, studies were grouped according to the nature of the intervention. Outcomes were then reported as changes to objectively or subjectively measured sitting time per day or per week. Changes to sedentary breaks were also reported where this information was available. Vote counting, based on direction of effect, was used to synthesise the included studies (Campbell et al., 2020) after which, an assessment on the certainty of evidence presented was reported in accordance with PRISMA guidelines (www.prisma-statement.org).

Table 3.1 Summary table of risk of bias assessments for included studies

	Sequence Generation:	Allocation Concealment:	Blinding	Incomplete Outcome Data:	Selective Outcome Reporting:	Control Group	Subjective Measures	Baseline Imbalances
Paw,CA. et al. (2006)	Low Risk	Unclear	Low risk	High Risk	Unclear	Low risk.	Low Risk	Unclear
Gardiner et al. (2011)	High Risk	High Risk	High Risk	Low risk	Unclear	High risk	Low Risk	N/A
Mutrie et al. (2012)	Low risk	Low Risk	High Risk	High Risk	Low risk	Low risk.	Low Risk	Low risk.
Chang et al. (2012)	High risk	High Risk	High Risk	Unclear	Unclear	Low risk.	High risk.	Low risk.
Burke et al. (2013)	Low risk	Unclear	High Risk	High risk	Low risk	Low risk.	High risk.	Low risk.
Fitzsimons et al. (2013)	High risk	High risk	High Risk	Low risk	Unclear	High risk	Low Risk	N/A
Matei et al (2015)	High risk	High risk	High Risk	Low risk	Low Risk	High risk	High risk	High Risk
Sjogren et al. (2016)	High risk	High risk	High Risk	Low risk	Low Risk	Low risk	High risk	Low Risk
Barone Gibbs et al. (2017)	Unclear	Unclear	Unclear	Low risk	Unclear	High Risk	Low risk	Low Risk
White, I. et al (2017)	Low risk	Low Risk	High risk	Low risk	Low risk	Low Risk	High risk	High Risk
Lewis et al. (2016)	High risk	High risk	High Risk	Low risk	High risk	High risk	Low risk	N/A
Fanning et al. (2017)	Low Risk	Unclear	Unclear	High risk	High risk	Low risk	Low risk	Low risk

3.3 Results

3.3.1 Study Characteristics

Searches of the electronic databases returned a total of 19,941 papers (Medline (Ovid): 12477; Exerpta Medica (EMBASE): 947; ProQuest (Health and Medical Collection and Physical Education Index): 2815; CINAHL; 3523; SBRN database: 179). An additional 26 articles were identified for review from the reference lists of full papers. After duplicates were removed (437), 19,530 papers remained. After screening titles and abstracts, 94 full papers were assessed for eligibility. A total of twelve articles met the inclusion criteria and were included in the review (table 3.1). Of the papers included, three studies originated in Australia, one in Korea, four in the UK, one in the Netherlands, one in Sweden and two in North America. Seven studies were randomised controlled trials and five used an uncontrolled pre-post-test design. Some of the main reasons for exclusion included participants aged under 60 years, studies that used low habitual PA as a proxy measure of SB, studies that were cross sectional and studies that did not comply with the SBRN (2012) definition of sedentary behaviour.

3.3.2 Participant Characteristics

The twelve studies comprised a total of 1335 participants (35% male, 65% female). Participation ranged from n=24 (Fitzsimons et al., 2013) in a small-scale feasibility pilot study, to n=478 (Burke et al., 2013) in a larger randomised controlled trial. All studies contained both male and female participants. Three studies reported socioeconomic status (Mutrie et al., 2012; Chang et al., 2013 Burke et al., 2013) and participants were sourced from broad educational backgrounds (primary through to college education) in nine studies (Burke et al., 2013; Chang et al., 2013; Gardiner et al., 2011; Mutrie et al., 2012; Matei et al., 2015; Lewis et al., 2016; Fanning et al., 2017; White et al., 2017; Barone Gibbs et al., 2017). Marital/ partnership status was also reported in eight of the studies (Burke et al., 2013; Chang et al., 2013; Gardiner et al., 2011; Mutrie et al., 2012; Chin A Paw et al., 2006; Lewis et al., 2016; White et al., 2017; Barone Gibbs et al., 2017). Although there were no inclusion restrictions on participants in residential care, only one study used participants in long term care (Chin A Paw et al., 2006). Participants in the other studies were independent community dwellers and participants were generally reported as healthy.

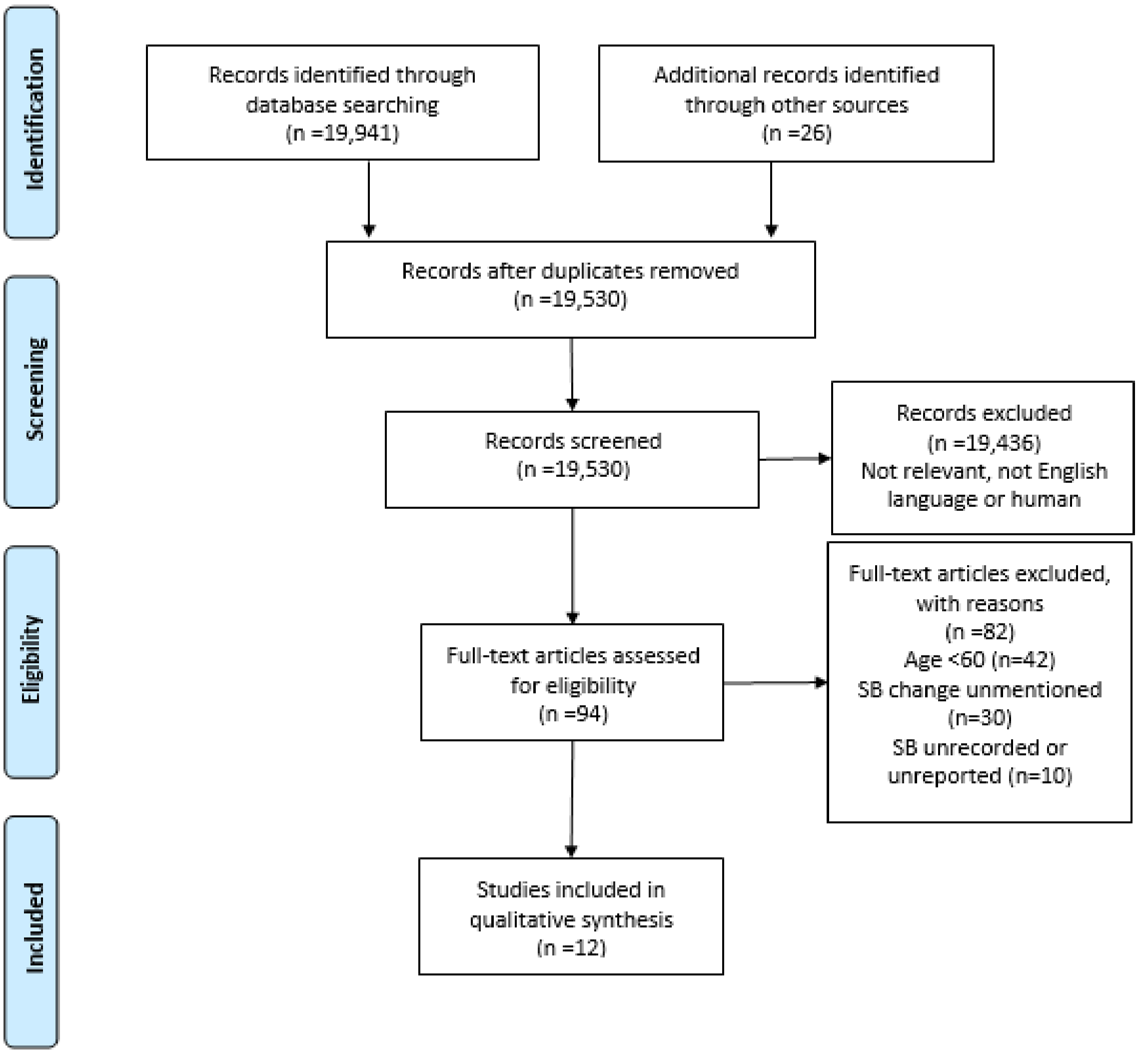


Figure 3.2 PRISMA flow chart of search results

Five studies reported disease characteristics (Chin A Paw et al., 2006; Burke et al., 2013; Chang et al., 2013; Lewis et al., 2016; White et al., 2017;) and only two (Burke et al., 2013; Lewis et al., 2016) reported co-morbidities, none of which affected the participants' ability to participate in the study.

3.3.3 Recording and Reporting of Sedentary Behaviour

Seven of the twelve studies included in this review used an objective measure of sedentary behaviour (Chin A Paw et al., 2006; Gardiner et al., 2011; Mutrie et al., 2012; Fitzsimons et al., 2013; Lewis et al., 2016; Fanning et al., 2017; Barone Gibbs et al., 2017). The activPal was the most commonly used objective measurement tool and was used in four studies (Mutrie et al., 2012; Fitzsimons et al., 2013; Lewis et al., 2016; White et al., 2017). This device allows the measurement of posture via an integrated inclinometer which can record sitting/lying postures and transitions between sitting/lying and standing. Three studies used uniaxial or triaxial (Actigraph GT3X) accelerometers to record sedentary behaviour (MTI 7164; Actigraph GT1M) and classified sitting time at a cut-point <100 counts.min^{-1} (Paw et al., 2006; Gardiner et al., 2011; Fanning et al., 2017). One study, Barone Gibbs et al. (2017), estimated sedentary time using proprietary algorithms taken from an accelerometer (SenseWear Pro) based on user-entered parameters to estimate energy expenditure. Sedentary time was calculated as the sum of awake minutes for which energy expenditure was ≤ 1.5 METs. This was in line with the definition for SB proposed by the SBRN (2012).

Subjective measurement tools were used to record SB in seven studies (Kallings et al., 2009; Chang et al., 2012; Burke et al., 2013; Fitzsimons et al., 2013; Matei et al., 2015; Barone Gibbs et al., 2017; White et al., 2017). The International Physical Activity Questionnaire (IPAQ) was the most common of these and was used to record sitting time in five studies (Kallings et al., 2009; Chang et al., 2012; Burke et al., 2013; Matei et al., 2015; White et al., 2017). Two studies (Matei et al. 2015 and White et al., 2017) used two subjective measures: Measure of Sedentary Time (MOST) and modified IPAQ to record SB. One study (Barone Gibbs et al., 2017) used an adapted form of the 'Coronary Artery Risk Development in Young Adults' (CARDIA) questionnaire. One study, Fitzsimons et al. (2013) used the Sedentary Behaviour Questionnaire (SBQ), which categorised data into nine distinct areas of SB. Although the measurement tools used to record SB varied, there was a high degree of homogeneity in the units used to report sedentary behaviour. Authors reported total sitting time and total sedentary time in minutes per day (n=5), hours per day (n=1) or hours per week, though Gardiner et al. (2011) and Lewis et al. (2016) also reported breaks in sedentary time and Fitzsimons (2013) reported on sub-categories of sedentary behaviours. Table 3.2 provides a summary and characteristics of the measures that relate to sedentary behaviour for individual studies.

3.3.4 Intervention Characteristics and Effects

The duration of interventions ranged from one, 45-minute face-to-face consultation with a six day follow up (Gardiner et al., 2011), to a 6-month exercise intervention (Kallings et al., 2009; Chin A Paw et al., 2006; Burke et al., 2013). One study used a 2-week intervention (Fitzsimons et al., 2013), one study used a 6-week intervention (Lewis et al., 2016), two studies used 8-week interventions (Chang et al., 2012; Matei et al., 2015), three studies used 12-week interventions (Mutrie et al., 2012; Barone Gibbs et al., 2017; White et al., 2017) and one study used a 6-month intervention (Fanning et al., 2017). All randomised controlled trials were a minimum of twelve weeks and a maximum of six months in duration. Three of the four shortest duration studies (Gardiner et al., 2011b; Fitzsimons et al., 2013; Matei et al., 2013) were pre-experimental or quasi-experimental in design and did not use a control group.

The interventions used by researchers displayed a high degree of heterogeneity. Three studies used only SB-specific BCTs (Gardiner et al., 2011; Fitzsimons et al., 2013; Lewis et al., 2016) to displace sedentary time. Two studies used a PA-specific behaviour change strategy

(Mutrie, 2013; Fanning et al., 2017) as the intervention. One study used SB and PA BCTs combined with both a site-based and a home-based exercise intervention (Chang et al., 2012). One study, Burke et al. (2013), used PA-specific BCTs combined with a home-based exercise programme (SB was not listed as an outcome variable in the published protocol for this study but was reported as an outcome in the subsequent randomised controlled trial). Kallings et al. (2009) used patient-centred counselling and individual home-based physical activity prescription in the study design. Three studies used a combination of SB and PA BCTs (Matei et al., 2015; Barone Gibbs et al., 2017; White et al., 2017) while one study reported on changes to sedentary time after exercise interventions alone (Chin A Paw et al., 2006). This information is summarised in Table 3.2. In every study where SB reduction was a primary outcome measure, the intervention included a behavioural change strategy.

Table 3.2 A summary of interventions used in studies in the review

Author	PA Interventions	SB Interventions	Mixed PA/SB Interventions	Change in SB Reported (*P≤0.05, **p≤0.01)
Paw et al. (2006)	✓			
Kallings et al. (2009)	✓			✓ **
Mutrie et al. (2012)	✓			✓ **
Burke et al. (2013)	✓			✓ **
Fanning et al. (2016)	✓			
Gardiner et al. (2011)		✓		✓ **
Fitzsimons et al. (2013)		✓		✓ *
Lewis et al. (2016)		✓		✓ *
Chang et al. (2012)			✓	✓ **
Matei et al. (2015)			✓	✓ *
Barone Gibbs et al. (2017)			✓	
White et al. (2017)			✓	✓

Table 3.3 Individual study characteristics related to SB outcomes

Author	Country	Study Design	Participants			SB Measure	SB Measurement Tool	Duration of Intervention	Nature of Intervention	Reported Change in Sedentary Behaviour Within-Study
			Total	Num. M/F	Mean (sd) Age or Age Range					
PA Interventions										
Chin A Paw et al., (2006)	Netherlands	RCT	157	M 31, F 126	81.7, range 64-94	Sitting time (min.day^{-1})	MTI 7164 accelerometer. Sitting defined as a cut-off point of 100 cpm.	6 months	Moderate intensity physical training in one of three groups: resistance training; all-round functional training; both; control group.	Change in median time spent sitting (min.day^{-1}) after 6-month intervention for all groups (median change [25th&75th percentile]: Resistance: -3 [-17;41]; Functional: -8 [-58;29]; Combined: 8 [-56;64]; Control: 0 [-31;19].
Kallings et al. (2009)	Sweden	RCT	101	M43, F58	68	Sitting time (min.day^{-1})	IPAQ	6 months	Individualised 'physical activity on prescription' (PAP) intervention.	Median change in sitting time (min.day^{-1}): intervention n group: 120; Control group: 60.
Mutrie et al. (2012)	UK	RCT	41	M 13, F28	Control 70 (4.3) Intervention 71.6 (6)	Sedentary time (min.day^{-1})	activPal	2 intervention meetings 12 weeks apart and a further 12-week follow up.	Physical activity consultation and walking programme	Reduction in sedentary time (min.day^{-1}) (95% CI) (Wk. 12-baseline) for: Intervention group: -47.9 (-70.2, -25.6); Control group:19.6 (-4.2, 43.4). (Wk. 24-wk 12) for: Intervention group: 6.9 (-21.2, 34.9); Control: -27.5(-56.5, 1.5).
Burke et al. (2013)	Australia	RCT	478	M 194, F 284	66.38 (4.09)	Sitting time (min.week^{-1})	IPAQ	6 months	Physical activity and nutritional recommendations based on Social Cognitive theory	Mean change in sitting time (min per week): Intervention: -355 min.week^{-1}; baseline 2063 (1050) post 1708 (952); Control group: 43 min.week^{-1} ; baseline 1691 (925) post 1734 (986).
Fanning et al., 2016	United States	RCT	221	M 50, F 171	Intervention 70.12 (4.79) Control 71.16 (4.62)	Total sedentary time, total sedentary breaks	Actigraph	6-month intervention, 6 month follow-up	DVD-based exercise sessions x 3 per week for 6 months with monthly feedback from exercise logs	Daily sedentary time reduced for intervention group: baseline - month 6 – month 12: 596.54 (96.4) – 593.49 (72.71) – 598.36 (84.54). Control: 586.21 (82.85) – 581.62 (76.07) – 585.66 (73.52.
SB Interventions										
Gardiner et al.(2011)	Australia	Pre-experimental (pre-post)	59	M15, F 44	74.3 (9.3)	Sedentary time (min.day^{-1}) & Sedentary breaks	Actigraph GT1M	1 x 45min session with 6-day follow up	Face to face intervention based on social cognitive and behavioural choice theory	Reduction in sedentary time (3.2%, 95% CI -4.18, -2.14) and significant increase in number of breaks in sedentary time per day (4.0, 95% CI 1.48, 6.58).
Fitzsimons et al. (2013)	UK	Pre-experimental (single group pre-post	24	M 14, F 10	68 (6)	Sedentary time (min.day^{-1})	activPal, SBQ (sedentary behaviour questionnaire)	2 weeks	Individualised consultation designed to change SB	Objectively measured SB reduced by 24 min.day^{-1}(2.2%). Median reduced time in subjectively measured SB of 8.6 min/day (16.6%).

Lewis et al., 2016	Australia	Pre-experimental (single group pre-post	27	M 10, F 17	71.7 (6.5)	Sitting time, sitting bouts,	activPAL, MARCA questionnaire	6 weeks	1x 1hour face to face interview using self-determination theory, followed by weekly telephone calls	Total sitting time reduced by 51 min.day^{-1}, standing increased by 38.5 min.day^{-1}. Sitting time in bouts $\geq$30 min reduced by 53.9 min.day^{-1}. Both significant at p,0.05.
Mixed Interventions										
Chang et al. (2012)	Korea	Quasi - experimental	48	M 21, F27	Intervention 66.67 (3.88) Control 66 (4.42)	Sitting time (min.week^{-1})	IPAQ	8 weeks	Empowerment theory and exercise intervention	Mean change in sitting time (min.week^{-1}) (SD): Intervention group: -543.33 (494.79); Control -60.45 (630.29).
Matei et al. (2015)	UK	Uncontrolled, 2 group, pre-post	43	M23, F 20	60-75	Sitting time (min/day)	MOST, modified IP AQ	8 weeks	Booklet designed to reduce SB and increase PA in two groups: sheltered housing (SH) group and community living (CL) group.	For SH group, mean sitting time per week increased throughout the timepoints (increase using IPAQ: 340 min.week^{-1}; 16%); using MOST: 565.6 min.week^{-1}; 23.1%). For group 2, mean sitting time decreased (reduction using IPAQ: 1056 min.week^{-1}, 39.2%; using MOST: 1000 min.week^{-1}, 28.4%).
Barone Gibbs et al. (2017)	North America	RCT	38	M 11, F 27	68.5 (6.7) & 67.3 (6.5)	Sedentary time (min.day^{-1})	Sense wear pro and modified CARDIA questionnaire	12 weeks	'Sit less' (SL) versus 'Get Active' (GA) interventions via telephone consultation	SL group: mean increase ($\pm$ SE) in sitting time (min.day^{-1}) for objective measure: 36 (18); mean reduction (25th and 75th percentile) in sitting time for subjective measure 54 (-120, 84). GA group: mean increase ($\pm$ SE) in sitting time (min.day^{-1}) for objective measure: 6 (14.4); mean reduction (25th and 75th percentile) in sitting time for subjective measure: 42 (-188, 188).
White et al. (2017)	UK	RCT	98	M 41, F 57.	60-74	Sedentary time (min/day)	Modified IPAQ and MOST questionnaires, activPal from participants in two London sites	12 weeks	Booklet promoting SB reduction and PA	Mean reduction in sitting time (min.day^{-1}) (95% CI) from baseline – 8 - 12 weeks: intervention using IPAQ reported 501.49- 435.43- 408.43; control reported 457.31- 426.03- 370.51; intervention using MOST reported 565.05 – 550.91 – 550.57; control reported 569.77 – 541.16 – 530.28. Statistical significance was not tested.

3.3.5 Methodological Quality and Intervention Effects

In this review, vote counting, based on direction of effect, was used to synthesise the included studies (Campbell et al., 2020). Overall risk of bias was assessed in the same manner as the individual domains. A high risk of bias in any domain was determined to have the same implication for the overall result, regardless of the domain in question. As a result, none of the studies included in this review were of high methodological quality (Table 3.1). The greatest risks to quality were: blinding of participants or assessors to the intervention (nine studies), followed by group allocation concealment (six studies) and allocation of participants to experimental or control groups (six studies). The highest risk of bias came from studies with no control group (Gardiner et al., 2011; Fitzsimons et al., 2013; Matei et al., 2015; Lewis et al., 2016; Barone Gibbs et al., 2017).

The twelve studies included in this review can be sub-divided into: seven behaviour change interventions (Gardiner et al., 2011; Mutrie et al., 2012; Fitzsimons et al., 2013; Matei et al., 2015; Lewis et al., 2016; Barone Gibbs et al., 2017; White et al., 2017), two exercise interventions (Chin A Paw et al., 2006; Fanning et al., 2016) and three multicomponent (combination of BCTs and PA) interventions (Chang et al., 2012; Burke et al., 2013), Kallings et al., 2009). The highest mean subjectively measured reduction in daily sedentary time for the intervention group was recorded during an 8-week intervention by Matei et al. (2015) at 150 $min.day^{-1}$, followed by an 8-week intervention by Chang et al. (2012) (77.6 $min.day^{-1}$), then a 6-month intervention by Burke et al. (2013) (50.7 $min.day^{-1}$). The highest mean objectively measured reduction in sedentary time was recorded over a six-week intervention by Lewis et al. (2016) at 51.5 $min.day^{-1}$, followed by a 12-week intervention by Mutrie et al., (2012) at 47.9 $min.day^{-1}$, then a 6-month intervention by Paw et al., (2006) at 8 $min.day^{-1}$.

Reduced sedentary time was a primary outcome goal in six studies and ten out of twelve interventions used some form of lifestyle education, behavioural change or counselling technique in the study design. Chin A Paw et al., (2006) and Fanning et al. (2016) used only activity-based interventions. Sedentary behaviour was a primary outcome goal in two of the three randomised controlled trials that reported no statistically significant reduction ($p \geq 0.05$) in sedentary time between the intervention and control groups (Paw et al., 2006; Fanning et al., 2016; Barone Gibbs et al., 2017).

3.3.6 Interventions That Used Behaviour Change Techniques to Reduce SB Only

Three studies: Gardiner et al. (2011), Fitzsimons et al. (2013) and Lewis et al. (2016) focused on individual participant consultations to displace sedentary behaviour and all three used goal setting and BCTs in the study design. In two studies (Gardiner et al., 2011 & Fitzsimons et al., 2013), participants were given visual feedback from accelerometer recordings of sedentary time to assist with targeting their behaviour. Lewis et al. (2016) used feedback from individual participant interviews to target SB. The approach was similar to Fitzsimons et al. (2013), who identified targeted behaviours via Sedentary Behaviour Questionnaire (SBQ) responses. This questionnaire sub-divided sedentary time into television time, computer games, listening to music, speaking on the telephone, reading, office work, playing instruments, arts and sitting while driving. Post intervention, the median recorded sedentary time (hours/week) had reduced in only two subdivisions; TV time (27 hours/week at baseline, to 21 hours/week post-intervention) and sitting while driving (6 hours/week at baseline, to 4 hours/week post-intervention). In two of these studies (Gardiner et al., 2011 & Fitzsimons et al., 2013), behavioural change was more successful at weekends than weekdays. Lewis et al. reported a reduction in total sedentary time of 52 $min.day^{-1}$ but they did not provide the context for the reduction (e.g. tv watching). Reductions in sedentary time were reported for all three studies and the effect sizes ranged from relatively small (4.18 $min.day^{-1}$ for Gardiner, 2011, $p \leq 0.01$) to moderate (24 $min.day^{-1}$ for Fitzsimons et al., 2013, $p \leq 0.05$; 52 $min.day^{-1}$ for Lewis et al., 2016, $p \leq 0.05$). None of the three studies was a randomised controlled trial and none used a control group, thereby limiting potential inferences for clinical effect.

3.3.7 Interventions Using BCTs to Reduce SB and Increase PA

In one RCT (Barone Gibbs' et al., 2017), the researchers focused on SB reduction with one intervention group ('Sit Less') and increased PA in the other ('Get Active'). Researchers used motivational interviewing, goal setting and problem solving during face-to-face and telephone contact for both groups. The authors reported a mean increase in objectively measured SB in both the 'sit-less' and 'get active' groups of 36 $min.day^{-1}$ and 6 $min.day^{-1}$ respectively after twelve weeks. Conversely, they reported a decrease in subjectively measured SB by both groups of 54 $min.day^{-1}$ and 42 $min.day^{-1}$ respectively, demonstrating a large discrepancy between data derived from objective and subjective measurements. The reduction in SB was not found to be statistically significant ($p \geq 0.05$).

Models of behaviour change were not consistent across the studies in this review. The Social Cognitive model (Bandura, 1986) of behavioural change was used by Mutrie et al. (2013) during two intervention consultations, along with a walking programme designed to increase PA through walking participation. This study did not target SB primarily, but it did target increased average daily step count and subsequently achieved a reduction of 47.9 $min.day^{-1}$ in objectively recorded SB after 12 weeks.

Matei et al. (2015) used the habit formation model (Gardiner et al., 2012) to inform a booklet designed to outline the risks of sedentary behaviour and the benefits of physical activity to participants who were recruited from two sources: warden assisted care facilities and independent community dwellers. The booklet offered tips and strategies to displace SB and promote PA habits. The basis of the habit formation theory is that habits are self-perpetuating, and the formation of a habit can prompt behaviour even in situations where motivation to perform the behaviour is low. This study reported a reduction in sitting time of 33.8% pre- post- intervention among the independent community dwellers ($p \leq 0.05$) but not among the warden assisted dwellers who increased their mean recorded sitting time by 16%.

White et al. (2017) used the habit formation model (Lally & Gardiner, 2013) model in a pilot RCT evolution of Matei's et al. (2015) uncontrolled study. Although the researchers reported an overall trend of reduced subjectively derived SB (mean reduction in sitting time was 53.8 $min.day^{-1}$), they used no inferential statistics to analyse the data because the study was not power tested to assess effect. In this study, a subsample of objectively derived data was collected using the activPal, but the data was not reported in the findings.

3.3.8 Interventions That Used Exercise Only to Reduce SB

Chin A Paw et al. (2006) used a resistance training and functional training intervention but no BCTs in their study design. Sedentary behaviour was a secondary outcome measure for this study, and they reported a mean reduction in sitting time of 3 $min.day^{-1}$ after a six-month physical activity intervention. Fanning et al. (2016) used a DVD-based exercise intervention to reduce SB. After 6-months of exercise undertaken every second day, SB was reduced by 3$min.day^{-1}$. Post-intervention, SB had returned to baseline levels at the six-month follow-up.

3.3.9 Multicomponent Interventions

The mean reduction in sedentary time recorded for these interventions was 82.76 $min.day^{-1}$ and the highest individual reduction was recorded by Chang (2013) at 77.6 $min.day^{-1}$. Chang (2013) used empowerment theory (Falk-Rafael, 2001) which consisted of four cornerstones: a. knowledge acquisition b. active participation c. social support d. skills improvement. A weekly 110-minute supervised exercise session was combined with 30 minutes of education on physical activity, sedentary behaviours, stress, medications smoking and alcohol consumption, diet and illness prevention. This was accompanied by a 40-minute group session on behavioural change where participants would reflect on health behaviours and set personal, attainable goals for physical activity or sedentary behaviour change over the coming week. Participants were also given a pedometer and were required to log exercise at home twice per week.

Although the initial value of SB was higher among participants in Chang's (2013) study, the percentage change in SB over the intervention period was similar to Burke et al. (2013) (17% reduction against 15.2% reduction in SB). Burke et al. (2013) used Social Cognitive Theory (Bandura, 1986) along with the Precede-Proceed Model (Green et al., 2005) in a randomised controlled trial, as the basis for a booklet designed for seniors. The booklet provided physical activity and nutritional recommendations and encouraged goal setting among participants. The study targeted increased PA and reported a significant ($p \leq 0.01$) reduction in SB of 50.7 $min.day^{-1}$ from baseline.

Kallings et al. (2009) used patient-centred motivational counselling alongside individualised prescription of home-based physical activity to encourage participants to meet recommended levels of PA and reported a significant ($p \leq 0.01$) median reduction in sitting time of 2h.day^{-1}.

3.4 Discussion

The aim of this review was to determine the effectiveness of interventions used by researchers that resulted in reduced sedentary time among older adults. Three of the studies included in this review did not target SB specifically (Mutrie et al., 2012, Burke et al., 2013, Kallings et al., 2009), yet recorded significant SB changes as a result of either PA or exercise interventions. In each of the three studies, a behavioural change strategy was also employed by the researchers. However, based on the low number and limited quality of eligible studies, and the low homogeneity of interventions, we conclude that there is insufficient evidence to determine the most effective means of targeting sedentary time in this cohort. Issues still to be resolved include: best practice guidelines for measurement of SB, measurement tools used to record SB, the duration of interventions used to target SB, the mode of interventions used to target SB, follow-up studies and definitions and descriptions of unhealthful SB.

While it is possible to estimate energy expenditure and record very low PA (≤1.5 METs) using proprietary algorithms derived from accelerometers, it is difficult to objectively determine whether very low PA satisfies the SBRN (2017) definition of sedentary behaviour without the use of an inclinometer to record posture. Four of the studies included in this review (Chin A Paw et al., 2006; Gardiner et al., 2011; Fanning et al., 2017; Barone Gibbs et al., 2017) used accelerometers with no inclinometer, and a reference point <100cpm to record sitting time, and only one of these (Gardiner et al., 2011) reported a significant reduction in SB. Tremblay et al. (2017) recommended that non-posture derived SB from an accelerometer should be regarded as stationary time, not sedentary time. Researchers have historically used an accelerometer cut point <100cpm to define SB but the accuracy of this figure has been called into question, particularly when used with older adults who habitually demonstrate low daily energy expenditure (Ezeugwu et al., 2015). The metabolic energy expenditure differential between SB and PA is smaller among older adults than it is among younger people. Ezeugwu et al. (2015) report that even 100cpm could represent light intensity activity for people with mobility impairments, hence the difficulty in accurately measuring changed behaviour and the increased risk of reporting errors in intervention studies that examine SB.

Only two studies (Fitzsimons et al., 2013; Barone Gibbs et al., 2017) used a subjective tool in addition to an objective measurement of SB. Fitzsimons et al. (2013) used the Sedentary Behaviour Questionnaire (Rosenberg et al., 2010) and found a 14.4% difference in the SB values recorded by both measures (both measures showed a decrease in median sedentary time). Barone Gibbs et al. (2017) used the CARDIA questionnaire (Gibbs et al., 2014). They reported a modest increase in objectively measured sitting time, in contrast to a subjectively measured decrease in sitting time reported in the same study, indicating a lack of agreement between the two measurement tools.

These studies illustrate two problems with current SB measurement techniques. The first is the use of accelerometers that may not be able to accurately detect SB in older populations in accordance with the SBRN (2012) definition. This can lead to a. potential measurement or reporting errors and b. studies that may be limited in analytical scope because they use only a subjective or an objective measurement tool. The second problem is that of subjective reporting of SB. Although subjective measurements of SB are cheaper to administer and more widely available to participants, they are also subject to over-reporting or under-reporting of sedentary time (Healy et al., 2011). Questionnaires also demand accurate recall of events which can be a problem for some older adults and Tremblay et al. (2017) report that the current crop of SB questionnaires demonstrate low levels of validity. One such questionnaire (International Physical Activity Questionnaire; IPAQ) was originally developed and validated for adults age up to sixty-five, but a modified version was used to record sedentary time with adults over that age in five of the studies here. The IPAQ does record sitting time but it does not categorise or sub-divide SB and requests only the total time spent sitting on weekdays and at weekends. Kang & Rowe (2015) report that SB is a complex set of behaviours, and that basic summary measures such as this do not provide enough data to inform targeted SB intervention strategies.

On the other hand, accelerometers provide more precise data than questionnaires but can be costly to administer, tend to be used with smaller sample numbers. Also, when used in isolation, accelerometers are unable to provide context for the data reported. Only four studies in this review (Mutrie et al., 2012; Fitzsimons et al., 2013; Lewis et al., 2016; White et al., 2017) used the activPal accelerometer, which incorporates an inclinometer, to measure SB. Two of these (Mutrie et al., 2012; Fitzsimons et al., 2013) reported a significant change in sedentary behaviour (White et al., 2017 did not use inferential statistics for data analysis but did report a reduction in objectively measured sitting time). Mutrie (2012) did not use an additional subjective measurement tool to record SB but Fitzsimons et al. (2013) used the SBQ (Rosenberg et al., 2010) and reported changes to SB in nine distinct areas, thus providing context for the activPal data. However, this was an unpowered pilot study using a sample of convenience, making it difficult to draw broader conclusions about the findings. Due to the complex nature of SB it seems important to know where SB arises so that interventions can target those behaviours.

There is some evidence that multi-faceted interventions are more successful than other formats in reducing sedentary behaviour. In this review, interventions that combined BCTs with increased PA and SB reduction led to a mean reduction in sitting time of almost twice that of BCT interventions alone. However, the durations of the interventions presented here were relatively short with no extended follow-up, so we cannot predict whether they promoted, or led to, longer-term behaviour change among participants. Nor can we draw conclusions on the clinical effect of reduced sedentarism among older people. Older adults who sit less and are more physically active experience lower mortality rates (Matthews et al., 2015), lower incidence of falls and fewer cardiometabolic risk factors (de Rezende et al., 2015). However, it is difficult to establish cause and effect here without further experimental trials, and studies using SB interventions have only begun to emerge in the literature. This is a weakness with the current crop of SB intervention studies. Long-term post-intervention monitoring of health outcomes resulting from SB interventions is warranted.

The evolution of this research is towards targeted SB reduction interventions. This can be achieved via BCTs that incorporate SB and PA interventions and use subjective and objective measurements. It is apparent in literature that attitudes to SB, social support systems and self-efficacy are predictors of SB status (Rollo et al., 2016). Also, habit formation has been linked with long term sedentary behaviours (Rollo et al., 2016). Consequently, studies designed to decrease SB are increasingly using interventions that seek to change short term cognitive and motivational factors, as well as PA and SB habits (Barone Gibbs et al., 2017; White et al., 2017).

SB has previously been poorly defined and cannot simply be defined as a lack of physical activity (SBRN, 2012). The most recent consensus statements (SBRN, 2012; SBRN, 2017) include a postural aspect to the behaviour and Kang & Rowe (2015) report a homogenous element to energy expenditure during sedentary behaviour that is not evident during physical activity. Bouts of very low energy expenditure can be represented by either breaks in physical activity or unhealthful or extended bouts of sitting, reclining or lying. However, the duration and number of bouts of SB that constitute unhealthful behaviour have yet to achieve consensus (Jansen & Cliff, 2015; Tremblay et al., 2017). Tremblay et al. (2017) acknowledge that standardised data reduction procedures for this do not currently exist but are important for future research. All the studies presented here reported on total sedentary time or sitting time. Only two studies (Gardiner et al., 2011; Lewis et al., 2016) reported on the number of breaks in sedentary time. The way in which sedentary time is accumulated may influence health outcomes (Janssen & Cliff, 2015). Therefore, patterns of SB and fragmentation of sedentary behaviour, along with reporting of sedentary bouts and breaks in sedentary time, warrant further investigation.

Although SB research has recently increased in volume, the low number of studies eligible for inclusion in this review illustrates that interventions for older populations are still in the early stages of development. Research indicates that sedentary behaviour should be targeted through BCTs, though a recommended strategy for behavioural change is still unclear.

3.5 Conclusion

Twelve intervention studies were eligible for inclusion in this review. All studies reported reductions in SB and three reported a reduction that was not statistically significant ($p>0.05$). The methodological quality of studies was generally low, but many were prospective trials/ small scale pilot interventions used to precede large scale studies. SB research among older people is still in its infancy and few high-quality studies have been published to date. Multicomponent approaches that combine BCTs with SB or PA designs may achieve more success in reducing sedentary time among older adults. However, whether PA interventions are well tolerated by older adults is still under debate. More cross-sectional studies have been undertaken in this area than interventions, and many interventions using older populations have reported changes to PA, not SB. Due to the complex nature of sedentarism, the categorising, sub-dividing and specific targeting of behaviours appears to be a key ingredient in SB reduction among older adults.

Chapter 4

Development of a behaviour change intervention designed to reduce sedentary behaviour among adults aged over 65 years.

4 Chapter 4

4.1 Introduction

In recent years, the association between adverse health outcomes and SB has been increasingly reflected in research and is now acknowledged in the latest WHO guidelines on physical activity and sedentary behaviour (WHO, 2020). SB reduction, alongside increased PA, is now widely recognised to confer health benefits on all age groups (WHO, 2020). Research into SB reduction among children has been conducted for many years (Gardner, 2016). However, interventions designed to reduce or displace SB among adults is more recent and researchers report varying degrees of success, partly because the research area is still young but also because heterogeneity in research design and SB measurement is high (Gardner, 2016). As previously outlined in Chapter 3, this heterogeneity is particularly evident among studies that seek to reduce sedentary time among older adults and few high quality studies using this section of the population are published. Consequently, there are no best practice guidelines from which to develop SB interventions for this cohort and additional studies that target SB, particularly non-purposeful SB, in older adults are needed.

To develop an effective SB intervention, researchers need to understand which intervention methods are effective for a particular cohort and why (Gardner, 2016). Subsequently, components of successful interventions need to be identified and then applied appropriately to new studies to ensure effectiveness. Intervention components have been described as 'intervention functions''', defined as 'broad categories of means by which an intervention can change behaviour' (Michie et al., 2014). Increasingly, behaviour change techniques (BCTs) have been employed by researchers as an intervention function to reduce SB among older adults. Interventions using BCTs have been defined as: "…coordinated sets of activities designed to change specified behaviour patterns" (Michie, 2011) and the primary purpose of a BC intervention is to change behaviour effectively (Michie, 2018). Evidence suggests that a change in behaviour is required to reduce sedentary time among older adults (Prince & Saunders, 2014) and that interventions targeting SB may be more acceptable and effective among adults than those that promote PA (Prince et al., 2014).

A change to behaviour that results in reduced SB initially requires knowledge of the correlates and causes of SB. Owen et al. (2011) developed a social-ecological model of SB that included social, organisational, environmental and policy determinants. More recently, Chastin et al., (2016) applied Owen's model to a multi-level process involving six clusters of factors responsible for SB: physical health and wellbeing, social and cultural context, built and natural environment, psychology and behaviour, politics and economics and institutional and home settings. The SITAUNOMY consensus taxonomy (Chastin et al., 2013) recommended consideration of the specific sedentary activity, its purpose, location, time and social setting to develop effective interventions for SB change. Researchers have begun to examine these determinants of SB and to design multi-level interventions to deal with SB in older populations.

The next step in the development process is to identify a mechanism by which we could intervene to reduce sedentary time. Various interventions are used in healthcare to address harmful or risky behaviours and it was previously thought that SB could simply be reduced with an increase in PA. However, it is now clear that different strategies are required to reduce SB than to increase PA (Prince & Saunders, 2014). Interventions that address the complexity of the SB problem and treat it organically (as a set of inter-related conditions) are more likely to achieve success than single-level interventions (Healy et al., 2017). SB reduction has been strongly linked with sense of achievement, social interaction and enjoyment of group-based activities (McGowan et al., 2018), further reinforcing a finding by Leask et al. (2015) that social isolation is a primary determinant of SB among older adults. As discussed in Chapter 3, there are currently no best practice guidelines for the development of SB interventions with older adults and researchers have met with varying degrees of success. However, the studies that were examined in Chapter 3 suggested that interventions seeking to change behaviour were more successful in achieving SB reduction than those that did not. Successful studies used BCTs to help participants form new habits, improve social support, increase self-efficacy and re-allocate non-purposeful SB.

A BC intervention benefits from a framework to systematically characterise and evaluate potential intervention mechanisms before using them to structuring a research study. In recent years, the Behaviour Change Wheel (Michie et al, 2011) has become widely used in healthcare as a framework for integrating behavioural theories with mechanisms for action. More recently, it has been used to help structure SB interventions (Gardner et al., 2016; Munir et al, 2018). However, at the time of writing, no published SB study with older adults had used the BCW to frame an intervention.

4.2 Using the BCW to Reduce Sedentary Behaviour with Older Adults

The Behaviour Change Wheel (BCW) was developed by Michie et al. (2011) as part of a multi-level model recognising that behaviour is part of an interacting system. It integrates nineteen of the most common frameworks of behaviour change as a resource for developing and evaluating BC interventions (see Chapter 1 for further discussion of the BCW).

There are three layers to the BCW. The inner layer uses a COM-B model (‘**C**’ capability, ‘**O**’ opportunity and ‘**M**’ motivation to engage in any ‘**B**’ behaviour) to determine sources of behaviour that could be used in targeted interventions. The second layer represents ‘functions’ (e.g. information or education), which indicate broad strokes by which an intervention could change behaviour. The outer layer represents seven types of policy that could be used to deliver the interventions. The BCW is often used in conjunction with the Theoretical Domains Framework (TDF), an expert consensus developed as a resource to synthesise key theoretical constructs in behavioural change into fourteen domains that could be used to inform the development of interventions (Cane et al., 2012; Michie et al., 2005).

In order to practically apply the BCW model and TDF to intervention design, Michie et al. (2014) advised that the intervention should be developed in eight steps, over three stages:

1. Stage 1: ‘Understanding the Behaviour’.
    a. Define the problem in behavioural terms
    b. Select target behaviour
    c. Specify the target behaviour
    d. Identify what needs to change
2. Stage 2: ‘Identify intervention options’.
    a. Identify intervention functions
    b. Identify policy categories
3. Stage 3: ‘Identify content and implement options’.
    a. Identify behaviour change techniques
    b. Identify mode of delivery

4.2.1 Stage 1: Understanding the Behaviour

a. Define the problem in behavioural terms

SB among older adults consists of a complex set of behaviours with similar energy expenditure and recent studies have sought to identify some of the main causes and determinants. For example, for older adults, the physical environment can be a barrier to standing and walking and can increase the risk of falling (Chastin et al., 2014), thereby reducing motivation to engage in even light PA. This is combined with increased incidence of inflammation and pain among older adults, which reduce mobility (Chastin et al., 2014). Poor weather restricts opportunities for older adults to go outside (Dontje et al., 2018) while a lack of places to rest and problems with public transport are cited as barriers to social interaction and community engagement (WHO, 2018b). When older adults do engage socially, activities regularly involve extended periods of sitting (Copeland 2019). To compound this problem, SB is often positively reinforced by influential peers and carers (Compernolle et al., 2019) and is viewed as a therapeutic opportunity to rest. Older adults are also more likely to be considered non-occupational and may therefore have more leisure time than other adults of normal working age. The combination of these factors are unique to older adults and may result in increased SB.

b. Select the target behaviour

SB can accumulate to 9.4 hours.day^{-1} among older adults and is a leading cause of ADL and physical impairment, morbidity and mortality (Clegg et al., 2013; Bowling et al., 2013). Older adults who are frail also tend to spend more time sedentary and this has been cited as a circular process (Blodgett et al., 2015). Owen (2011) identified leisure time, transport, occupation and household as the four domains where SB was most likely to occur in adults although older adults (65+) are more likely to be non-occupational. Sedentary time was therefore selected as the target behaviour for the intervention.

c. Specify the target behaviour

Leask et al. (2015) found that 70.1% of older adults' sedentary time occurred at home and cross-sectional evidence points to older adults spending non-purposeful and unhealthful sedentary time alone, in the afternoons and usually in front of a screen (Harvey et al., 2015; Leask et al., 2015). The behaviours to be targeted in this intervention were therefore non-purposeful sedentary time. (sitting/ lying) spent at home in the afternoons. Screen time (particularly television watching) was also targeted as a source of non-purposeful SB in this study. A reduced total sedentary time, reduced number of sedentary bouts and displacement of non-purposeful sedentary time for more purposeful behaviour including PA were seen as important aspects of SB reduction.

d. Identify what needs to change

Sedentary behaviours are deeply rooted in older adults' daily lives (Compernolle, 2019) and may be reinforced by increased leisure time, social norms and the influence of peers (Chastin, 2015), making change more difficult. It has also been suggested that older adults may not be aware of the difference between SB and inactivity (Compernolle, 2019), which can influence the ability of participants to change behaviour appropriately. SB knowledge and awareness may also influence responses to questions within self-report tools and the accuracy of inferences made from subjective measurements like questionnaires (Compernolle, 2019). In addition, evidence indicates that older adults are unaware of the risks posed by SB and can demonstrate low motivation to make changes to sitting time (Munir et al., 2018). This also needs to be addressed within a SB intervention.

Table 4.1 illustrates how the capability, opportunity and motivation of participants is linked with domains of behaviour (TDF) (Michie et al., 2014), which in turn are linked to the main determinants of SB requiring consideration in intervention designs. Determinants of SB that are relevant to older adults are listed in the 'relevance of domain' column and are based on those reported by Chastin et al. (2015) and Dontje et al., (2018)

Table 4.1 Link between COM-B and the theoretical domains framework

COM-B	TDF	Relevance of Domain To SB
Physical Capability	Physical skills	Functional capacity, pain and health status will determine potential for success
Psychological Capability	Knowledge	People lack knowledge of SB effect or how to reduce SB
	Cognitive and interpersonal skills	Displacing non-purposeful SB with purposeful SB
	Memory, attention & decision	Need to notice duration of sitting time and remember to change posture periodically
	Behavioural regulation	Participants should develop skills of self-monitoring, goal-setting, planning.
Physical Opportunity	Environmental context & resources	Physical environment needs to be suitable or to change to enable SB reduction
Social Opportunity	Social influences	Influence of others could be important. Peer, group support and family influences are important
Reflective motivation	Social role and identity	Social role is already well developed in community groups. Not as important at home.
	Beliefs and capabilities	Important for self-efficacy. Also relates to knowledge of SB and effects.
	Optimism	As above
	Beliefs about consequences	Maintenance or improvement in function should increase motivation to succeed
	Intentions	Relates to planned behaviour and should strengthen with increased self-efficacy
	Goals	Setting goals (daily/weekly) and evaluation may be important
Automatic Motivation	Reinforcement	Regular reinforcement of SB reduction strategies may be important in habit formation.
	Emotion	Emotional response required for increased motivation.

4.2.2 Stage 2 Identifying Intervention Options

a. Identify Intervention Functions

The next step in the process was to identify intervention functions (the broad strokes for intervention design) suitable for this population. Michie et al. (2014) identified nine of the most commonly used intervention functions from nineteen of the most common frameworks of behaviour change: education, persuasion, incentivisation, coercion, training, restriction, environmental restructuring, modelling and enablement. In a systematic review of behaviour change strategies used in SB reduction interventions with adults, Gardiner et al. (2016) found that the most promising BC interventions with adults contained functions associated with social or physical environmental restructuring, persuasion and education. The most successful interventions also included self-monitoring and problem-solving tasks to enable and encourage self-regulation of changed behaviour. From the studies reviewed in Chapter 3, successful interventions included those that used individual consultations (Gardiner et al., 2011; Fitzsimons et al., 2013; Lewis et al., 2016), problem solving (Barone Gibbs et al., 2017), goal setting (Barone Gibbs et al., 2017), education (Matei et al., 2015) and self-monitoring though SB feedback (Gardiner et al., 2011; Fitzsimons et al., 2013).

The success of any behavioural change intervention will be influenced by participants' capability, opportunity and motivation to change behaviour (Michie, 2011) and an intervention should be subject to a prior evaluation of these elements of the BCW. Michie et al. (2014) included an evaluation mechanism within the COM-B model. to ensure relevance and quality in intervention design. The criteria for the evaluation are based on **A**ffordability, **P**racticability, **E**ffectiveness and cost-effectiveness, **A**cceptability, **S**ide-effects/safety, **E**quity of the functions (APEASE). Each BCT in this study was examined to ensure that the APEASE criteria were met before initiating the intervention.

b. Identify policy categories

The next step in the development of the intervention was to identify which policies would support the delivery of the intervention functions identified in Stage 2a. Michie et al., (2014) identified seven policy categories that could represent decisions made by authorities to support and enact interventions. The policy categories most suited to this intervention were 'communication', 'guidelines', 'regulation', environmental/ social planning' and 'service provision'. *Communication* related to the format for delivery of the intervention which would be conducted in both print and oral format. The intervention group would have regular contact with the researcher and feedback could be provided in both oral and written format. *Guidelines* related to the documents that would be used to enable the intervention, from a powerpoint presentation used to educate and inform participants, to a diary of SB, used to record behaviours for the purpose of cognitive recall and group interaction. *Regulation* related to the establishment of guidelines for conduct during the intervention and incorporated meeting and assessment schedules for participants. Environment/ social planning referred to the control and manipulation of the physical and social environment to enable the participants to successfully undertake the intervention and reduce SB. *Service provision* related to the delivery of the intervention by the researcher, physical space for assessment and consultation as well as the weekly support system put in place for group interaction and social support. Other policy categories such as *Fiscal measures* and *legislation* were not deemed to be important to the delivery of this intervention.

4.2.3 Stage 3 Identify content and implement options

a. Identify Behaviour change techniques

The final stage of development involved identification of the behaviour change techniques (BCTs) to be used and the mode of delivery. Michie et al. (2014) defined a BCT as 'an active component of an intervention designed to change behaviour'. BCTs must be "observable, replicable and irreducible and used as the mechanism for change" (Michie, 2014). Intervention functions identified in Stage 2, that were suitable for older adults, were individually linked with frequently used BCTs from Michie et al., (2014), Gardner et al (2016) and with successful interventions in Chapter 3. The APEASE criteria (Michie et al., 2014) were then used to evaluate the practical application of the BCTs to the intervention. Finally, policies suitable for the delivery of the BCTs were considered. This process is summarised in Table 4.2

Several options were available for implementation of the intervention. In this case, the community groups to be approached were within driving distance, which enabled face to face delivery of the intervention. Also, due to the inclusion of social support as a mechanism for change, it was decided to deliver the intervention at the group, rather than the individual, level. Human support has been cited as the most important component in effectiveness and adherence of BC interventions (Santarossa et al., 2018). Face to face delivery allows a researcher to facilitate interactive discussions and engage with participants, thereby helping to improve the efficacy of the intervention (Carey et al., 2012).

In summary, the intervention was designed to incorporate five 'functions' found by the Gardiner et al., (2015), in combination with the systematic review, to be most promising in reducing sedentary behaviour among adults. The functions used in this study were 'education', 'persuasion', 'training', 'environmental restructuring' and 'enablement' and were informed by Michie's (2014) COM-B (capability, opportunity, motivation and behaviour) model for behaviour change intervention design

The intervention functions were initially incorporated into a single, 30-minute powerpoint presentation (appendix 18) and group discussion to be delivered face-to-face by the researcher at the beginning of Week 1, to the intervention group in the following format:

a. *An introduction and a short question/answer session* - to establish and enhance participants' knowledge of SB and the relationship between SB, barriers to activity and health outcomes.
b. *Education function* – this was designed to improve the participants' level of knowledge on SB and health consequences. It included an information session on the rise of sedentary behaviour among older adults, risks associated with SB and advice on monitoring SB in daily life.
c. *Persuasion function* – this was designed to invoke an emotional and personal response to SB change. It included highlighting the dangers of SB and the benefits of reducing sedentary time. Participants were prompted to ask questions and engage in discussion.

Table 4.2 Summary of BCTs and intervention functions, assessed using APEASE criteria

Intervention Function	Most Frequently used BCTs Within Function	BCTs Meet APEASE Criteria?	Policies To Deliver The BCT
Education	1.Information about social/environmental consequences. 2.Information on health consequences. 3.Feedback on behaviour 4.Feedback on outcome of behaviour. 5.Prompts/cues 6.Self-monitoring of behaviour	**Yes**. All group members to take part initially in a 30-minute interactive class and to meet once each week to discuss the intervention and planned changes for the following week. Prompts and cues based on researcher-led suggestions and group suggestions for behavioural changes.	1.Communication via powerpoint and participant information sheets, weekly meetings, SB diary. 2.Guidelines via written information sheet, group suggestions and researcher-led oral communication. 3.*Service provision* - via initial presentation and meetings with the researcher at the community centre each week. Private room allocated for the purpose of the intervention.
Persuasion	1.Credible source 2.Information about social/ environmental consequences 3.Information about health consequences. 4.Feedback on behaviour 5.Feedback on behaviour outcomes.	**Yes.** This can be done as part of the class and weekly discussion. Can also be facilitated via peer and group support throughout each week. Participants to be given feedback on actual and proposed changes to behaviour and group members encouraged to participate in the feedback process.	
Training	1.Demonstration of behaviour 2.Instruction on performing behaviour 3.Feedback on the behaviour & outcomes. 4.Self-monitoring	**Yes**. Via classroom activities and discussion. Attempting known, new or untried methods to reduce SB may also improve retention and efficacy. Gradual change encouraged to encourage retention.	

	5.Behavioural practice/rehearsal.		
Environmental Restructuring	1.Restructure the physical/social environment. 2.Prompts/ cues 3.Adding objects to the environment	**Yes**. Via prompts and feedback from weekly discussion. Participants can use the information sheet and group suggestions for further restructuring of physical and social environment	1.*Environmental/social planning* - via restructuring of social environment to decrease time alone and to the physical environment to spend less time in environments where non-purposeful SB may occur 2.Guidelines via presentation and information sheets provided 3.Service provision via weekly face-to-face presence enables discussion and
Enablement	1.Social support (unspecified & practical) 2.Goal setting (behaviour & outcome) 3.Adding objects to the environment. 4. Restructure the physical environment 5.Self-monitoring of behaviour 6.Review goals (behaviour and outcome) 7.Problem solving 8. Action planning	**Yes.** Via weekly meetings. Researcher and participants to review SB diaries and discuss options for following week. Participants to discuss ideas/ changes made from previous week. Problems with achievement/ enablement discussed and researcher to enable group to provide suggestions and solutions	

d. *Training and environmental restructuring function* – this was designed to facilitate individual participants to change social and physical behaviour. It included prompts and cues that could be used in normal daily life to alter the social and physical environment in order to reduce sedentary behaviour
e. *Enablement function* – the presentation was designed to give participants the confidence and tools to achieve SB reduction immediately, via a list of suggested behavioural changes and short term goal setting. Researcher-led suggestions using the information sheet (appendix 18) would provide participants with methods to incorporate SB reduction into daily life. Participants were encouraged to set personal goals for the forthcoming week and to monitor and review sedentary time daily.

At the end of the presentation, participants would be provided with a copy of the presentation (appendix 18) and an information sheet (appendix 18). The sheet included a summary of the presentation to aid with recall and a list of hints and tips for reducing sedentary behaviour throughout the week. Participants would be encouraged to choose one item from the list (or to introduce something else to the list) and focus on SB reduction for the following week.

Self-regulation and enablement via social support were reported to enhance motivation among participants (Gardiner, 2015). Therefore, a blank template was developed to encourage participants to keep a written record of SB changes throughout the week (Appendix 20). Each week (weeks 2-6), the group would meet for fifteen minutes, use the completed template as a prop to discuss SB displacement and share ideas/goals for SB reduction in the forthcoming week. The template was designed to improve retention and recall of SB reduction among the group. The weekly meetings were designed to share new ideas, maintain social support for the intervention, improve participants' self-efficacy through peer support and promote enablement of SB reduction via prompts from the researcher.

At the end of the 6-week intervention, participants were no longer required to maintain a record of SB changes or to meet each week. Participants in the control group were not required to meet, would receive no feedback from the assessments until after the study was completed and were not given access to either the presentation, SB weekly diary or the SB reduction hints/tips until after the study was completed.

4.3 Conclusion

Michie et al. (2014) advocated a systematic and structured approach to the development and evaluation of interventions that involve behaviour change. The BCW advocated by Michie et al. (2011) is widely used in healthcare settings and is appropriate to use in the development of an SB intervention for older adults. In this case, five intervention functions were identified (environmental restructuring, persuasion, education, self-monitoring and problem-solving), along with eighteen associated BCTs that could be delivered face-to-face, in a group setting (information about social consequences, information about environmental consequences, information on health consequences, instruction on performing behaviour, feedback on behaviour, feedback on outcome of behaviour, prompts/cues, self-monitoring of behaviour, goal setting behaviour, goal setting outcome, review goals, problem solving, credible source, behavioural practice/rehearsal, adding objects to the environment, restructure the physical environment, restructure the social environment, social support). The next chapter reports the delivery of the intervention to a group of adults aged over 65 years.

Chapter 5

Intervention Study

The Effect of a Sedentary Behaviour Reduction Intervention on Sedentary Behaviour and Sedentary Context Among Adults Aged Over 65 Years

5 Chapter 5

5.1 Introduction

Older adults are reported as the least physically active members of the population and engage in sedentary behaviours (SB) on average 9.4 hours per day (Harvey et al., 2015). Long and frequent bouts of SB represent a significant risk factor for mobility disability (Gennuso et al., 2013; Tremblay et al., 2010) morbidity, mortality (de Rezende et al., 2014; Wirth, 2016) and health-related quality of life (HRQOL) (Boberska et al., 2018) among older people, independent of the risks posed by physical inactivity (PA) alone (Kang & Rowe, 2015). Although PA is normally categorised by increasing levels of intensity (e.g. low, moderate, vigorous), SB is an umbrella term for any time spent in sitting or lying postures (Dall et al., 2017) because a similar energy expenditure exists during SB that is not evident during PA (Kang & Rowe, 2015). A consensus statement published in 2012, and updated in 2017, defined SB as: "any waking behaviour characterised by energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture." (Tremblay et al., 2017).

Although extended bouts of sitting, reclining or lying are considered unhealthy at any age, not all SB is harmful to the overall health of older adults. Bouts of very low energy expenditure can also be represented by breaks in physical activity, purposeful social interaction or engagement in cognitively demanding activities that contribute to positive mental health and quality of life for older adults (Leask et al., 2015). It is therefore important, in the design of SB interventions, to disentangle unhealthful sedentary time from breaks in PA and purposeful sitting. However, the type, duration and number of SB bouts that constitute unhealthy behaviour have yet to achieve consensus (Jansen & Cliff, 2015; Tremblay et al., 2017; Boberska, 2018). A draft taxonomy developed by Chastin et al. (2013) offered a top-level categorisation of SB under the acronym SITONAUMY (purpo**S**e, env**I**ronment, pos**T**ure, s**O**cial, measureme**N**t, **A**ssociated behaviour stat**U**s, ti**M**e, t**Y**pe). The taxonomy proved useful in the identification of unhealthful SB in a recent paper by Leask et al. (2015), in which researchers reported that approximately 70% of sedentary time occurred in the home (followed by transport at 35.2%). The researchers also reported that most non-purposeful SB was recorded during leisure time (49.2% of sedentary time), in the afternoon, when alone and often involved screen time. An 'ecological model' of SB habits developed by Owen (2012) also identified the home environment as the most likely, of four key domains, to be the source of most prolonged SB for older adults.

Recently, researchers have used behaviour change techniques (BCTs) to reduce SB among older adults. Studies have focused on various theoretical frameworks of behaviour to inform intervention design. These include: empowerment theory Chang et al. (2013), social cognitive and behavioural choice theories (Gardiner et al., 2011; Mutrie et al., 2012; Roberts et al., 2019), self-determination theory (Lewis et al., 2016), the habit formation model (Matei, 2015; Matson et al., 2018) and self-regulation theory (Kotlyn et al., 2019). Recently Michie et al. (2014) introduced the COM-B (**C**apability, **O**pportunity or **M**otivation - **B**ehaviour) model as an interdisciplinary guide to designing BC interventions in a variety of contexts. The model synthesises nineteen frameworks of behaviour change that form a 'Behaviour Change Wheel'. The wheel is used to identify practical intervention options that can be applied to changing any or each of the main components of behaviour. Thus far, no study has used this combined approach to intervention design for community-dwelling older adults. The heterogeneity in current intervention studies indicates that more research is needed to establish the best model or mechanisms for change in this cohort

SB interventions have been designed to reduce sitting time (Harvey et al., 2018; Koltyn et al., 2019), displace sedentary time via increased physical activity (Mutrie et al., 2012) or to do both (Chang et al., 2012; Burke et al., 2013). Researchers have reported findings ranging from no change in SB (Burke et al., 2013; Harvey et al., 2018) to large effects in favour of reduced sedentary time (Gardiner et al., 2011; Chang et al. 2013; Koltyn et al., 2019). However, most of the findings come from low quality studies. To date, heterogeneity in research design has been too high, and sample sizes too small, to conduct a high-quality meta-analysis on SB interventions with older adults. Larger-scale research interventions with older adults are difficult to undertake due to problems with recruitment across the spectrum of physical function, high participant dropout rates and low adherence to intervention requirements (Biddle et al., 2018). Therefore, high-quality studies are needed so researchers can pool data to establish which interventions work best with this section of the population. Additionally, although cross-sectional evidence indicates an association between SB and physical function in older adults, there is little evidence to suggest a dose-response relationship. Additional studies needed to further investigate this relationship.

The ideal duration for SB reduction intervention has yet to be determined. The National Institute for Clinical Excellence (NICE) has suggested that interventions need to be feasible, practical and affordable, while maximising effectiveness for participants and minimising burden (NICE, 2014). Brief health-based interventions can range from a few seconds, in an 'ask – advise – assist' format to those that are delivered over weeks or months (NICE, 2014). SB interventions with older adults have demonstrated success over one session with a 6-day follow-up (Gardiner et al., 2011), one session with a 2-week follow up (Fitzsimons et al., 2013), four weeks with a 4-week follow-up (Kotlyn et al., 2019), six weeks (Lewis et al., 2016), ten weeks with a 4-week follow-up and 6 months with a 6-month follow-up (Fanning et al., 2016). There is currently no consensus on the optimum duration for SB reduction; nor is there any evidence to suggest that the intervention duration determines the degree of SB reduction. However, the duration of recent interventions that use self-monitoring, goal-reviewing and social support have exceeded single session interactions (Harvey et al., 2018; Kotlyn et al., 2019; Roberts et al., 2019). NICE (2014) recommend that 'extended brief interventions' (those conducted over 30 minutes or more and delivered over a number of sessions) are delivered to people who are assessed as being at increased or higher risk of harm or who are involved in risky behaviours. Kotlyn (2019, p75) commented that 'there is a need for feasible, effective interventions that can be disseminated into real world community health programmes for older adults.'

Additional intervention studies are needed to determine the most appropriate mechanism and dose required for a contextually relevant and clinically meaningful reduction in SB for older adults. It is also important to determine which intervention techniques are likely to be successful and why. A recent review of BC interventions conducted with adults (Gardiner et al., 2016) found that the 'most promising' strategies for BC involved studies that focused on environmental restructuring, persuasion or education. Self-monitoring, problem solving and restructuring the social or physical environment were particularly promising BC 'functions' used within these interventions.

A key element in SB study design is the ability to accurately measure both the time spent sitting/lying and postural change. Historically, this has been problematic because early accelerometers did not incorporate inclinometers to assess posture and therefore heterogeneity in SB measurement was high. Valid tools that are sensitive enough to accurately measure SB and capture changes in SB are still needed (Copeland et al., 2017). The bulk of SB measurement is currently achieved either subjectively via questionnaire, objectively via accelerometry, or more uncommonly, using both methods. Questionnaires are inexpensive to administer and can be made widely available to participants, but they are also subject to over-reporting or under-reporting of sedentary time (Healy et al., 2011; Copeland et al., 2017). They also demand accurate recall of events which can be difficult for some older adults and Tremblay et al. (2017) report that the current crop of SB questionnaires demonstrate low levels of validity. On the other hand, accelerometers provide more accurate and precise data than questionnaires but can be costly to administer, tend to be used with smaller sample numbers and, when used in isolation, are unable to provide context for the data recorded (Kang & Rowe, 2015). Researchers could consider using both forms of measurement, to provide both accuracy and context for quantities and patterns of SB.

5.2 Aim

The primary aims of the study were to:

1. To determine whether a 6-week behaviour change intervention (based on education, persuasion, environmental re-structuring and social support) would lead to objectively measured SB reduction among older adults.
2. To repeat measures 4-weeks post-intervention and assess whether any change in behaviour was maintained.
3. To provide a more detailed picture of the quantity and context of SB in older adults.

5.3 Experimental Design

This was a randomised controlled trial that examined the effect of a 6-week targeted behaviour change intervention and four-week follow-up on a group of community dwelling older adults (aged 65 years or older). The study was approved by the Ulster University Research Ethics Committee (REC/19/0031, July 2019).

5.3.1 Sample Size

For a fully powered RCT, a calculation of sample size for a two-armed trial using individual randomisation was initially made using the formula proposed by Charan & Biswas (2013). Using the Normal deviate for Type I error of 0.05 ($Z_{\alpha/2}$ =1.96, 2-tailed), combined with the Normal deviate for Type II error of 0.8 ($Z_{1-\beta}$ =0.84), a mean objectively measured sitting time of 534 $min.day^{-1}$ and a population effect size of 52 $min.day^{-1}$ $\pm$SD 114.1 $min.day^{-1}$ (based on Lewis et al., 2016), a sample size of 75 participants per arm, over two arms (intervention and control) was required to achieve 80% power at α 0.05 according to the equation:

$$N= 2\delta^2(Z_{1-\beta} +Z_{\alpha/2})^2 / (\mu_0- \mu_1)^2$$

With a potential dropout of approximately 25% (Lewis et al., 2016), a fully powered trial would require a total of 188 participants.

5.3.2 Participants

Community dwelling participants (n=37, age 65-80yrs) were recruited from older adults' community groups in Northern Ireland and the Republic of Ireland via informal meetings at community events. Participants were permitted to take part if they were medically stable, community dwelling, independent living male and female adults aged $\geq$65 years.

Participant recruitment took place in July 2019. Initial expressions of interest were followed by a recruitment information sheet outlining the purpose and details of the study, the researchers involved and the supervisory team. This was followed by a participant information session one week later. The experimental design, protocols and risks were explained to participants at the meeting, after which queries were answered and informed consent was taken. At this time, participants were screened for inclusion and exclusion criteria. Participants were permitted to withdraw from the study at any time without reason or justification. See figure 5.1 for a CONSORT diagram relating to the study.

5.3.3 Experimental Protocol

All eligible older adults from three community groups that agreed to take part in the study were invited to participate. Anthropometric measures (height and body mass) were determined at baseline using a free-standing stadiometer (Holtain Ltd, UK) and standard laboratory scales (Seca Delta, Germany). The three community groups constituted three clusters. Due to the number of participants recruited, two of the community groups were amalgamated into one cluster group (total n=20), and the other community group were treated as one larger cluster (n=22). Clusters were randomly allocated (randomisation by cluster group using a random number table) to either the SB intervention (IG) or to act as controls (CG). Both groups were monitored for SB on three occasions (at baseline (T0), at T1, immediately following the intervention and at T2 and four weeks post-intervention) over the 10-week study period via an accelerometer (activPAL micro, PAL Technologies, Glasgow, Scotland) and the Sedentary Behaviour Questionnaire (SBQ, Rosenberg, 2010). Control group participants were asked to make no changes to their normal daily routine during the study period and were instructed to continue with normal activities of daily living. Group allocation was not concealed from the research team or participants and the researcher was not blinded to allocation of participants to the intervention or control groups

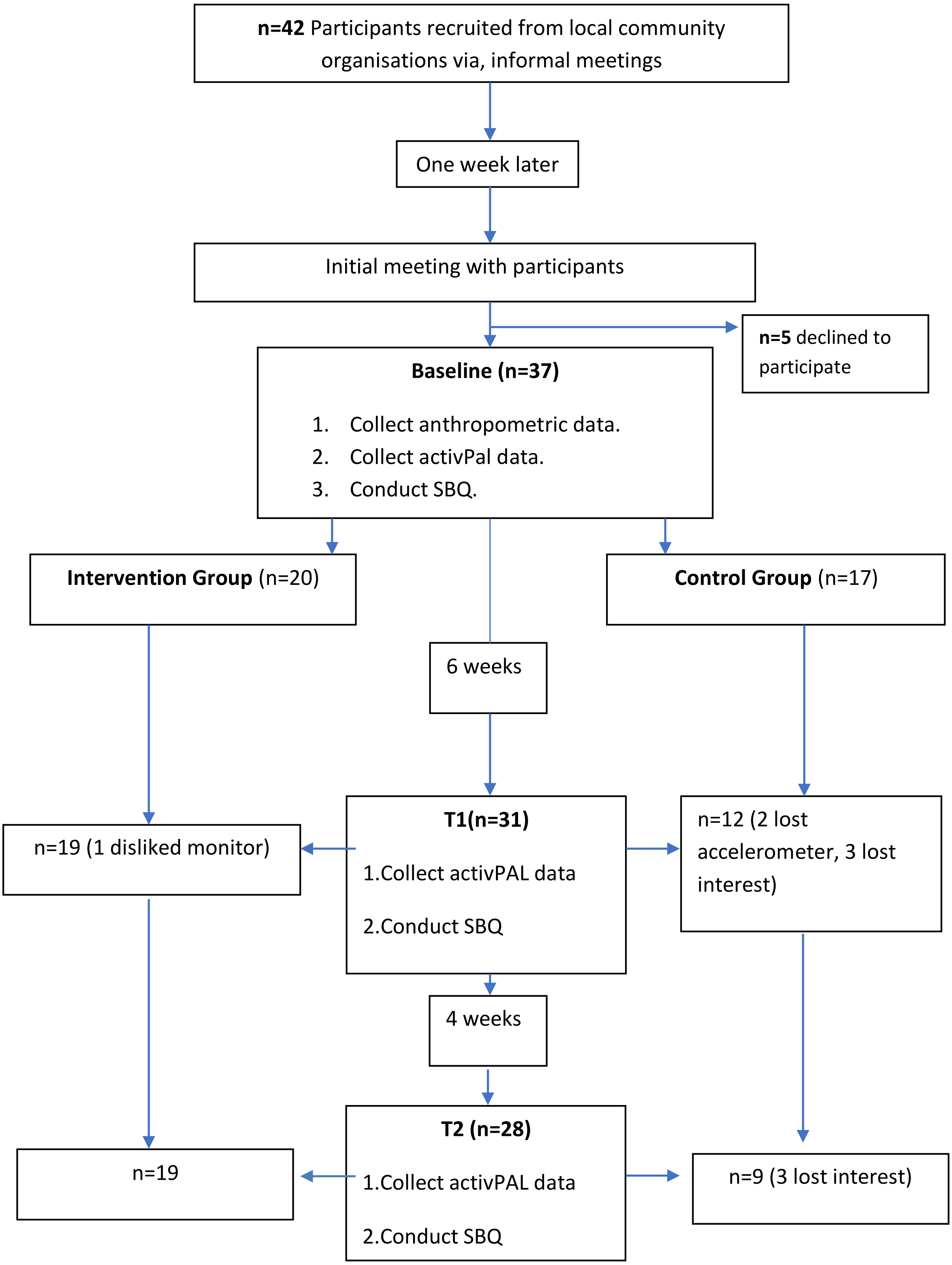


Figure 5.1 CONSORT diagram for intervention study

5.3.4 Quantitative Measurement of SB

A body-worn accelerometer (activPAL micro, Physical Activity Technologies, Glasgow, Scotland) was used to record objectively measured SB. The activPAL accelerometer is matchbox sized and extremely lightweight. The device uses information gained from static acceleration and limb angle to record posture (via the accelerometer) while dynamic acceleration of the device determines movement. The accelerometer is not waterproof, so it was covered with a medical grade waterproof jacket and wrapped in a Hypafix (Hypafix, BSN medical) medical grade adhesive patch. It was then attached directly to the midline of the right thigh using another Hypafix patch. Each participant was provided with three additional unused adhesive patches in case the device became detached.

Participants were then asked to wear the device continuously (including during water-based activities) for a period of seven days and were provided with a demonstration and information leaflet to assist with application and wear. Edwardson et al. (2017) reported that compliance was higher when users were required to wear the device continuously than with non-continuous protocols. Users were advised to remove the device and seek medical advice if they experienced skin irritation from the adhesive patch. The activPAL was used to record sedentary time per day, total steps per day and time spent in sedentary bouts, with at least four days required for data analysis (Edwardson et al., 2017). Devices were initialised before distribution to participants. The default sampling frequency of 20Hz was used with a default minimum duration of 10s sitting/ lying or standing required to register a new event. Data was collected at baseline, T1 (week 6) and T2 (week 10) and was processed using PALanalysis v8.11.2.54 and the Enhanced analysis algorithm (CREA) (PAL Technologies Ltd, Glasgow, UK) with auto-correct engaged for inverted wear.

5.3.5 The Sedentary Behaviour Questionnaire

The SBQ (Rosenberg et al., 2010) is a standardised survey tool, commonly employed to assess time spent in nine different behaviours (watching television, playing computer, listening to music, sitting talking on the phone, doing paperwork, sitting reading, playing a musical instrument, arts and crafts and sitting on transport) identified as sedentary (Appendix 17). It is broadly used in both clinical and non-clinical settings and is designed to measure the functional status of healthy, community dwelling adults. It has also been used as a tool to record sedentary time and context with older adults (Fitzsimons et al., 2013) and can easily be administered by lay personnel or health and fitness professionals. Questionnaire data was collected at baseline, T1, (week 6, end of intervention) and again at T2 (week 10).

5.3.6 Outcome Measures

The primary pre-post- intervention outcome measures for this study were:

1. Changes to objectively measured total sedentary time, time spent in SB bouts over 30 minutes, time spent in SB bouts over 60 minutes, total sit-to-stand transitions and total steps, all using the activPal for data collection.
2. Identification of, and changes to, subjectively measured sedentary context using the SBQ.

A secondary outcome measure was to investigate changes to sedentary time reflected in the SBQ and to compare subjectively reported SB (using the SBQ) with objective data collected using the activPal.

Feedback to participants on the activPAL data and questionnaires were not made available until after the study was completed so that participants were blinded to their outcomes at each stage during the intervention and follow-up periods. The level of agreement between objective and subjective SB measures over the intervention and follow-up periods was also analysed. The time spent in each behaviour (reported in the SBQ) provided the context for SB.

5.3.7 Statistical Techniques

Statistical analyses were performed using SPSS V.25.0 (SPSS Inc, Chicago, Illinois, USA). Continuous data is presented as means and standard deviations (individual SB results, height, body mass, age), and numbers and percentages for categorical data (gender). Histograms and stem and leaf plots were used to examine normality of distribution of continuous variables. The data was analysed using independent T-tests to examine differences between groups in demographics at baseline. A 2 x 3 (group & time), repeated measures analysis of variance examined differences in sedentary time, sedentary bouts, breaks in sedentary time and total steps following the intervention and across the follow-up period. A bivariate correlation analysis and Bland-Altman plot examined the relationship, and agreement, between self-reported and objectively measured sedentary time. A regression analysis was also performed to determine the existence of proportional bias between objective and subjective measures.

5.4 Results

5.4.1 Recruitment and Retention

Forty-two participants from three community groups were approached and agreed to take part in the study (n=20, IG, n=22, CG).

The main exclusion criteria were as follows:

- Not willing or unable to participate (e.g. not signing an informed consent).
- Not living independently or living in institutional care.
- Unable (physically or mentally) to receive and understand simple instructions on operation of measurement devices and descriptions of study parameters.
- Diseases known to impair cognitive function balance or movement including: Parkinson's disease (stage 3 onwards), stroke (with reduced balance and mobility), M.S. (resulting in reduced balance and mobility), amputation of upper or lower limbs, dementia, osteoporosis (causing movement impairment), rheumatoid arthritis (causing movement impairment), osteoarthritis (causing movement impairment), hip fracture and Alzheimer's disease (Howe et al., 2011).
- Habitual use of psychotropic medications.

After the initial meeting to explain the study in detail, five participants from the control group declined to participate further. Participants were then randomly allocated to either the intervention (IG) or control groups (CG) by community group (cluster randomisation) to avoid cross-contamination between groups. Participant retention across all three time points was excellent (95.2%) for the intervention group (one participant disliked the accelerometer and withdrew) but was poor (52.9%) for the control group (2 participants lost accelerometers and declined to participate further, 6 lost interest in the study). Nine participants remained in the control group at T2 (4-week post-intervention follow-up). The CONSORT diagram (Figure 1) shows the participant flow throughout the study and details the dropout rates and reasons for dropout at each stage of the process. IG participation in the group discussions over the six-week period was excellent (100% attendance for retained participants) but SB record keeping was poor (5% of SB-change records were kept throughout the week) and participants preferred to discuss SB changes at the group meetings.

5.4.2 Participant Demographics

Forty-two participants were initially recruited for the study, from which thirty-seven (30 males, 7 females; mean age 71.8 $\pm$ 13; IG n=20, CG n=17) were assessed at baseline. There were more male than female participants. All members of the intervention group and 50% of the control group were male (a total of three older adults' groups were recruited, two groups were entirely composed of males). Baseline demographic values for each group are shown in Table 5.1

Table 5.1 Participant characteristics at baseline

Participants	**IG (n=20)**	**CG (n=17)**	**All (n=37)**
Age (yrs)	70.1 (5.92)	73.7 (4.15)	71.8 (5.42)
Height (cm)	176.4 (8.57)	168 (8.12)	172.8 (9.18)
Body Mass (kg)	91.4 (31.51)	73.6 (12.49)	83.2 (25.96)

Presented as mean (SD).

5.4.3 Intervention Effects for Objectively Measured SB

The BC intervention effect on SB, adherence to SB change, and displacement of SB were evaluated using a 2x3 repeated measures ANOVA for each of five objectively measured variables (total steps per day, total SB, total time in SB bouts over 30 minutes, total time in SB bouts over 60 minutes and total number of sit-to-stand transitions). Three time points were entered for each variable: T0 (baseline), T1 (post-intervention) and T2 (4 weeks post-intervention). 'Time' was the within-subjects factor (3 levels: T0, T1, T2), and 'Group' was the between-subjects factor (2 levels: treatment vs control). The mean objectively measured SB figure for all participants, in both groups at baseline, was 531.8 $min.day^{-1}$ (SD 110.2). Table 5.2 shows a summary of the findings from a complete case analysis, confining the analysis to cases with no missing values. Further discussion on imputed data takes place later in this section.

Table 5.2 A summary of repeated measures ANOVA outcomes reported at baseline, T1 and T2

Treatment	Baseline	T1	T2	Effects within (Time[1]), between (Group[2]), and interaction (Group*Time[3]).
Total Steps (steps.day^{-1})				
Intervention (n=19)	8150.6 (3206.6)	8431.8 (3950.1)	6737.7 (2833.4)	$F_{2,52}$= 2.30, p=0.11[1]
Control (n=9)	8704.0 (2817.9)	8818.3 (2422.5)	8382.1 (2320.8)	$F_{1,26}$ =0.60, p=0.44[2]
All (n=28)	8328.5 (3045.8)	8556.0 (3489.2)	7266.2 (2749.5)	$F_{2,52}$=0.84, p=0.44[3]
Total SB (min.day^{-1})				
Intervention (n=19)	565.2 (97.9)	542.3 (115.5)	560.8 (128.4)	$F_{2,52}$=0.08, p=0.92[1]
Control (n=9)	461.9 (102.7)	482.1 (84.9)	455.1 (120.9)	**$F_{1,26}$=4.62, p=0.04 η^2=.151**[(2)]
All (n=28)	531.8 (109.2)	522.9 (108.9)	525.8 (133.6)	$F_{2,52}$=1.50, p=0.23[3]
Total time in SB bouts over 30 min (min.day^{-1})				
Intervention (n=19)	276.2 (105.9)	271.9 (124.6)	294.5 (156.0)	$F_{2,52}$=1.08, p=.35[1]
Control (n=9)	201.6 (100.9)	207.0 (56.1)	227.5 (119.2)	$F_{1,26}$=2.36, p=0.14[2]
All (n=28)	252.3 (108.4)	251.0 (110.6)	272.9 (146.5)	$F_{2,52}$=0.04, p=.956[3]
Total time in SB bouts over 60 min (min.day^{-1})				
Intervention (n=19)	154.1 (102.9)	141.6 (104.3)	148.0 (142.9)	*$F_{1.58,39.54}$=.55, p=0.54[1]
Control (n=9)	95.8 (83.8)	93.0 (52.0)	116.6 (97.5)	$F_{1,25}$=1.29, p=0.27[2]
All (n=28)	134.7 (99.3)	125.4 (92.1)	137.6 (128.5)	*$F_{1.58,39.54}$=0.45, p=0.60[3]
Sit to Stand Transitions (no. transitions.day^{-1})				
Intervention (n=19)	38.5 (11.0)	39.5 (9.7)	35.3 (10.5)	$F_{2,52}$=2.37, p=0.08[1]
Control (n=9)	41 (9.6)	44.3 (6.8)	41.3 (5.7)	$F_{1,26}$=1.7, p=0.06[2]
All (n=28)	39.3 (10.5)	41.0 (9.1)	37.3 (9.6)	$F_{2,52}$=0.60, p=0.02[3]

*Mean (SD), F_{df} and p values for outcomes within and between participants, reported at T0, T1 and T2. *Data for time spent in sitting bouts over 60 min did not meet Mauchly's test of sphericity (p=0.025) so Greenhouse-Geisser values are reported for this outcome variable.*

Total steps - A small increase in total steps pre- to post-intervention of 281 steps.day^{-1} (3.5%) for the intervention group was accompanied by a reduction in total objectively measured SB of 22.9 min.day^{-1} (4.05%), suggesting that SB may have been displaced by additional stepping activities. However, the reduction in total SB was not maintained post-intervention and within-subjects variance between timepoints was too low ($F_{2,52}$= 0.08, p=0.92) to be significant. The change in SB for both groups between timepoints is illustrated in Figure 5.2.

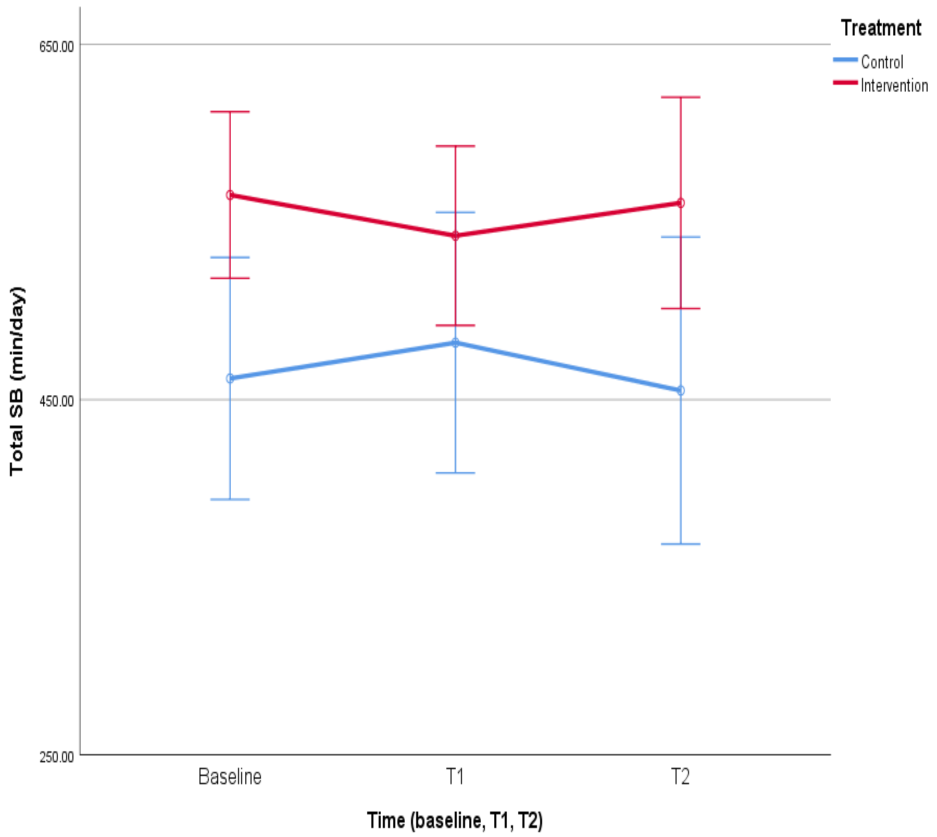


Figure 5.2 Total SB for both groups at baseline, T1 & T2 (with 95% CI error bars)

Although within-subjects variance was low for total SB, between-groups variance was significantly higher for this variable ($F_{1,26}$=4.62, p=0.04, η^2=0.151), demonstrating a small effect in favour of the intervention group. However, the change was not maintained post-intervention and Total SB returned close to baseline values at T2 (4-week post-intervention). The interaction effect between groups over time for Total SB was very low ($F_{2,52}$=1.50, p=0.23**,** partial η^2=0.06). Similarly, there was no group x time interaction for Total Steps ($F_{2,52}$=0.84, p=0.44, partial η^2=0.03**)**, Total Time in SB Bouts over 30 min ($F_{2,52}$=0.04, p=.956, partial η^2=0.004**)**, Total time in SB bouts over 60 min ($F_{1.58,39.54}$=0.45, p=0.60, partial η^2=0.02**)** and Sit To Stand Transitions ($F_{2,52}$=0.60, p=0.02, partial η^2=0.02**).**

As part of the BC intervention, participants were encouraged to reduce the total time spent in each bout of SB as well as the total number of daily SB bouts. Results in Table 5.2 illustrate that, although the time spent in SB bouts over 1hr in duration decreased by 12.5 $min.day^{-1}$ at T2, the change was not maintained. Also, the number of transitions from sitting to standing did not decrease, suggesting that the number of SB bouts did not reduce and were largely maintained over the intervention period. This is illustrated in Figure 5.3 where the error bars show considerable crossover between data at each time point.

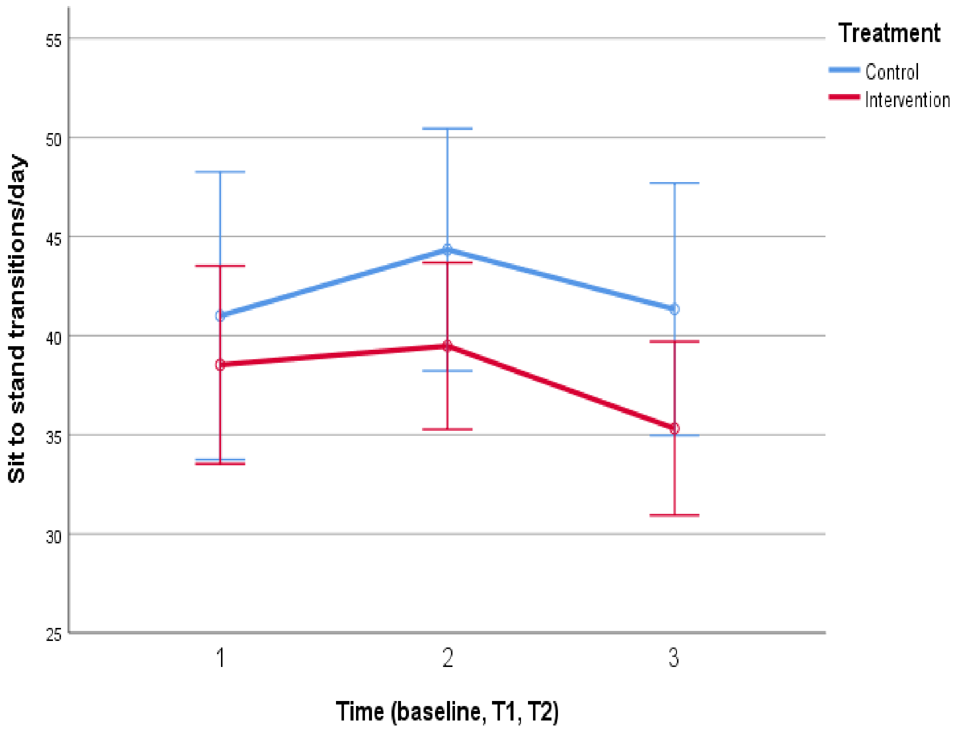


Figure 5.3 Change in sit-to-stand transitions for IG and CG at baseline, T1 & T2 (with 95% CI error bars)

Baseline differences were evident between the intervention and control groups in both the SB and PA variables e.g. total SB (565.2 min.day^{-1} vs 461.9 min.day^{-1}) and total steps (8150.6 steps.day^{-1} vs 8704 steps.day^{-1}). To investigate these differences further, an ANCOVA was performed on SB and total steps, using the treatment group as the covariate for between-subjects effects. The results showed a small effect for group for SB **(**$F_{1,26}$=4.61, p=0.041) and little effect for total steps ($F_{1,26}$=0.60, p=0.44).

To account for the considerable dropout in the control group (9 participants remaining at T2 from 17 at baseline), and subsequent missing data (participants were assumed missing at random) at timepoints T1 and T2, an imputation analysis was undertaken for two variables (total steps and total sitting per day) to investigate whether a completed data set could affect the findings from the original model. The group means for each variable, at each timepoint, were used as the imputed figure for missing data on each occasion (Jakobsen et al., 2017). Results showed a small effect for Total Steps within-group (time) ($F_{2,70}$=2.30, p=0.11) and low interaction effect for time*treatment ($F_{2,70}$=2.05, p=0.14). Total sitting demonstrated a similarly low within-group ($F_{2,70}$=0.85, p=0.43) and interaction effects ($F_{2,70}$=1.89, p=0.16), suggesting that higher retention of participants may not have improved the overall outcomes.

5.4.4 Intervention Effects and Context for Subjectively Measured SB

The Sedentary Behaviour Questionnaire (SBQ) was mainly used to provide context for the objectively measured sedentary time in this study. Table 5.3 provides a summary of the average daily sedentary time reported by participants in each of the nine separate categories included in the questionnaire.

Watching television was consistently the highest rated category of SB, comprising approximately 33.6% of total sedentary time at baseline. This was followed by transport (18.9%) and paperwork (12.2%). On average, playing instruments (1.1%), arts and crafts (4%) and talking on the telephone (4.3%) were the lowest rated SB categories. Time spent watching television remained relatively constant over the course of the week whereas time spent on paperwork during the week was displaced mainly by reading and talking on the phone at weekends. Figures 5.4 & 5.5 illustrate the mean division of sedentary time reported by participants at baseline, by category, for weekdays and for weekends.

Table 5.3 Mean(SD) self-reported SB from the SBQ at baseline, T1 & T2

	Baseline		T1		T2	
Time (hr.day^{-1})	**Intervention**	**Control**	**Intervention**	**Control**	**Interventio n**	**Control**
Television watching	3.27 (1.34)	2.21 (1.42)	2.67 (1.21)	1.94 (1.96)	2.62 (1.01)	1.46 (1.61)
Computer	0.46 (0.43)	0.19 (0.43)	0.17 (0.38)	0.56 (1.40)	0.37 (0.95)	0.21 (0.45)
Listening to Music	0.79 (0.84)	0.54 (0.72)	0.80 (0.6 2)	0.71 (1.31)	0.70 (0.69)	0.55 (1.10)
Telephone	0.38 (0.44)	0.66 (0.78)	0.44 (0.56)	0.44 (0.47)	0.46 (0.45)	0.29 (0.40)
Paperwork	0.78 (0.99)	0.73 (1.08)	0.77 (1.13)	0.68 (1.13)	0.68 (0.94)	0.57 (1.03)
Reading	0.92 (0.83)	0.85 (1.17)	1.17 (0.91)	0.56 (0.77)	1.08 (0.61)	0.40 (0.87)
Playing Instrument	0.10 (0.48)	0.15 (0.38)	0.08 (0.24)	0.13 (0.38)	0.025 (0.08)	0.15 (0.48)
Arts/Crafts	0.36 (0.59)	0.72 (1.01)	0.64 (0.93)	0.84 (1.45)	0.56 (0.81)	0.46 (1.11)
Transport	1.91 (1.55)	1.00 (0.86)	1.59 (1.04)	0.80 (0.91)	1.59 (0.80)	0.79 (1.15)
Total SB	8.91 (2.67)	7.93 (4.92)	8.34 (2.64)	10.50 (6.34)	7.93 (1.95)	9.51 (6.32)

At T1 and T2, participants were blinded to the results from previous questionnaires. The results appeared consistent across both SB categories and timepoints, suggesting a good degree of reliability in the questionnaire. Participants within the intervention group reported a reduction in total SB of 6.4% (34.2 min.day^{-1}) from baseline to T1 and 11% (59.4 min.day^{-1}) between baseline and T2. However, this continued reduction in sedentary time post-intervention was not reflected in the objective measurements, indicating disagreement between perceived and objectively measured sedentary time.

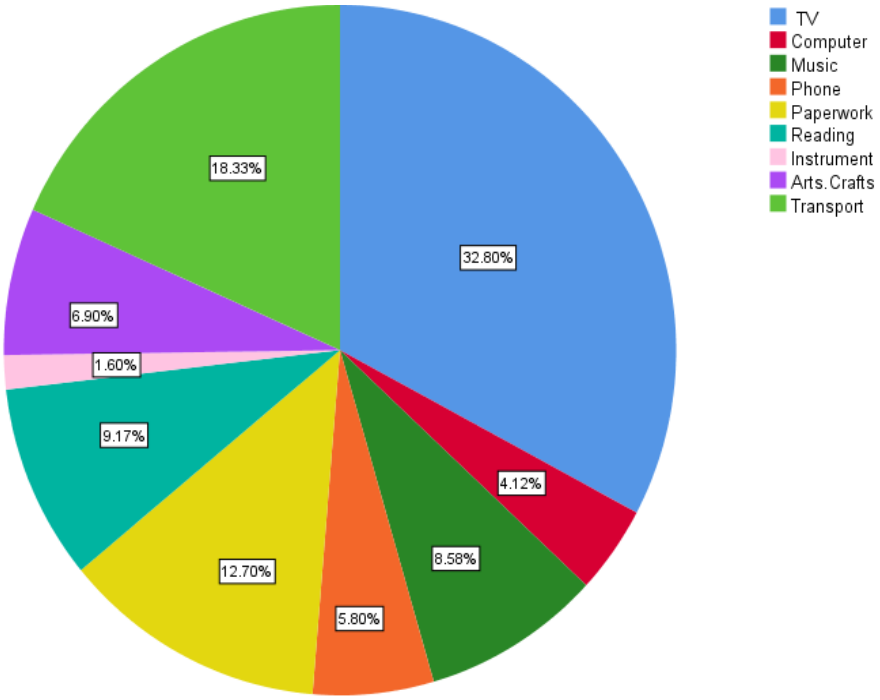


Figure 5.4 Relative contribution of SB context to overall SB for all participants on weekdays at baseline.

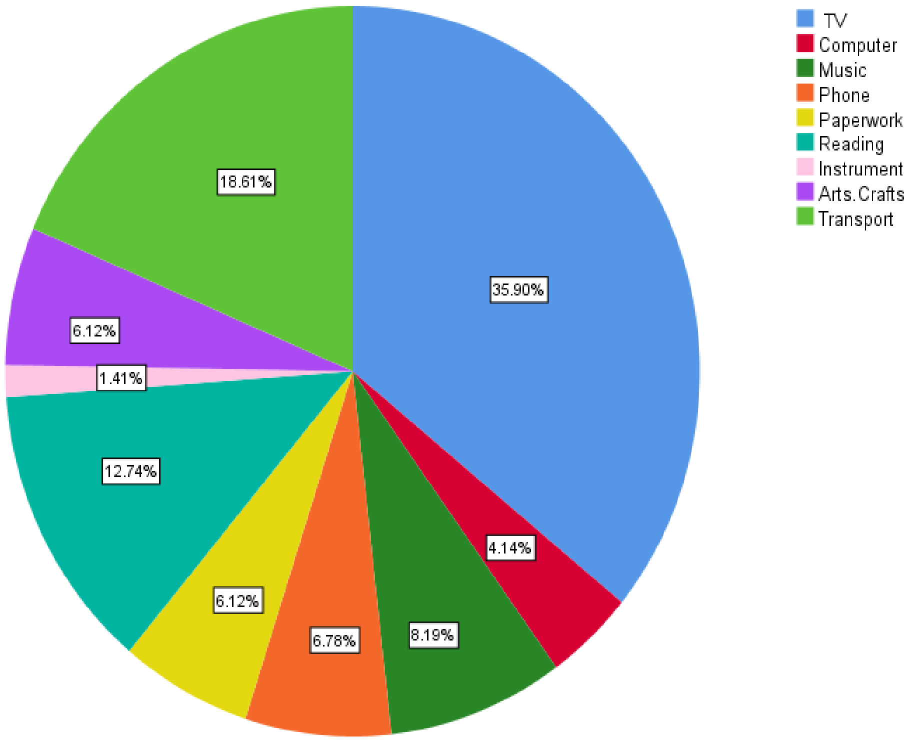


Figure 5.5 Relative contribution of SB context to overall SB for all participants on weekends at baseline

The level of agreement between objective (activPAL) and subjective (SBQ) measures of sedentary time appeared high at baseline (35.6 $min.day^{-1}$ difference) and a bivariate analysis revealed a significant, moderate correlation at this time point ($r=0.36$, $p<0.05$). However, the level of agreement reduced at each subsequent time point, with a reported difference of 119 $min.day^{-1}$ at T2 ($r=0.16$, $p>0.05$). Table 5.4 illustrates the difference between measures at each stage of the study.

Table 5.4 Difference between objectively-derived and subjectively-reported SB

	Objective (activPAL) Baseline	**Subjective (SBQ) Baseline**	**Diff.**	**Objective (activPAL) T1**	**Subjective (SBQ) T1**	**Diff.**	**Objective (activPAL) T2**	**Subjective (SBQ) T2**	**Diff.**
Total Daily SB ($min.day^{-1}$)	531.8	496.2	**35.6*** ($r=0.36$, $p<0.05$)	522.9	466.2	**58.6** $r=0.26$, $p>0.05$	525.8	406.8	**120.1** $r=0.16$, $p>0.05$

*(Pearson's r, significance *p<0.05)*

A Bland & Altman plot (figure 5.6) was drawn to quantify the level of agreement between the objective (activPAL) and subjective (SBQ) measures of SB at baseline and and to investigate the possibility of proportional bias between the two measures. The plot seeks to quantify the mean difference and construct limits of agreement between the measures using the means and standard deviation between them. The y axis demonstrates the difference between the paired measurements and this is then plotted against the mean of the two measures, represented by the x-axis. An ideal model, using two highly reflective measures, would reveal zero differences. However, this was not the case here and differences between the measures were evident. The most precise measurements were taken using the activPAL so this was considered to be the reference measurement against which the SBQ data was compared. The plot revealed firstly that the majority of data points lay within the limits of agreement.

Although data points were scattered above and below the zero line, a difference in the spread of data points in the scatterplot indicated a small level of bias (activPAL data demonstrated a tendency to be quantitatively higher). A subsequent regression analysis demonstrated an t-value of -2.81 ($p<0.05$), thereby demonstrating some proportional bias between measures.

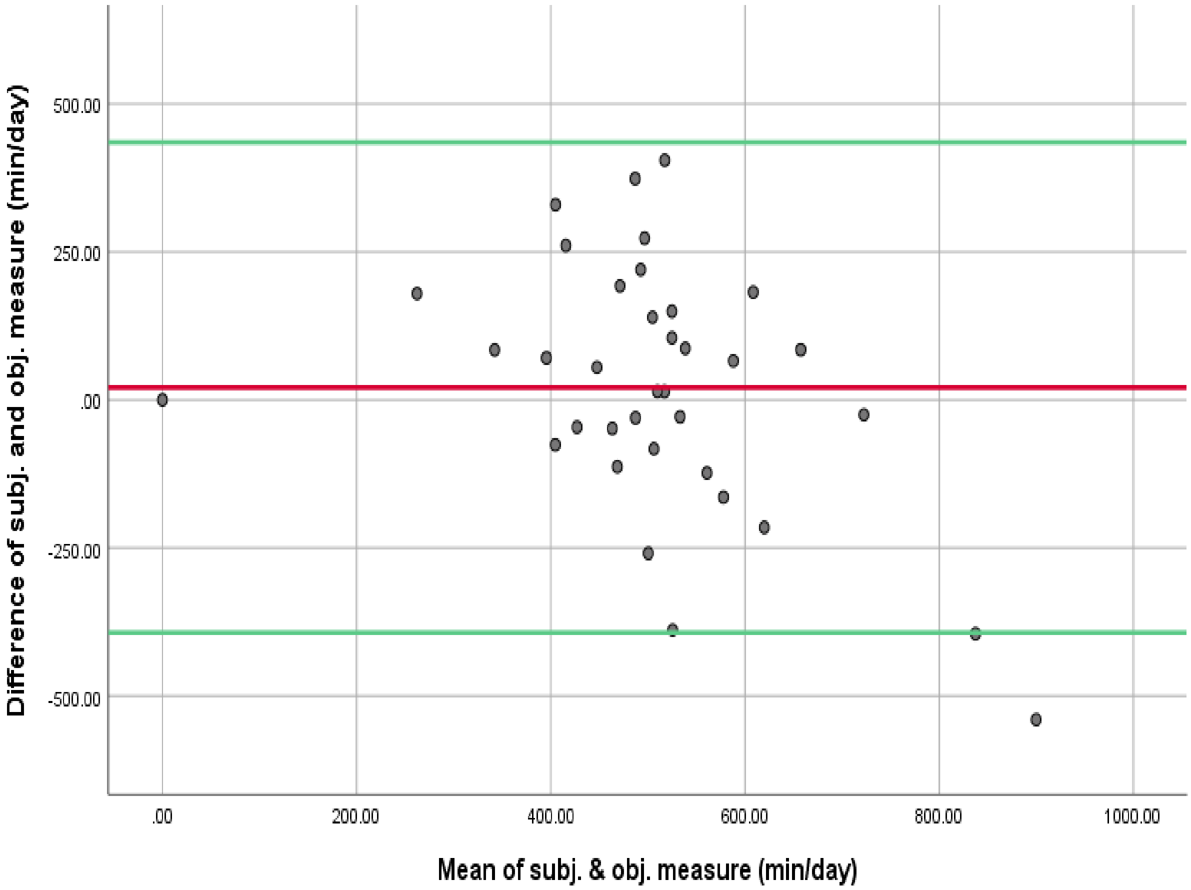


Figure 5.6 A Bland-Altman plot showing the difference (min.day^{-1}) between paired SB measures against average (min.day^{-1}) of SB measures (with upper and lower 95% CI bars)

5.5 Discussion

This study investigated whether a multi-level behavioural change intervention, based on education, persuasion, training, environmental restructuring and enablement, could reduce or displace sedentary time in community dwelling older adults. The study also aimed to better identify the context in which SB took place. Overall, the findings demonstrated a small reduction in SB for the IG over the 6-week intervention period. However, the group x time interaction effect was too low to be significant and the reduction was not maintained over the 4-week follow-up, at which time SB returned to pre-intervention levels.

There is a growing body of research recommending a reduction in daily SB for all children and adults. SB is considered an independent risk factor for poor physical and mental health (Dogra et al., 2017) metabolic dysfunction (Gennuso, 2013) and premature mortality (Engeroff, 2017; Ekelund et al., 2019) in old age. Older adults who are physically active consistently display higher levels of physical function than their sedentary counterparts (Harvey et al., 2015), though there is not enough evidence to determine this association as cause and effect.

Recent evidence suggests that interventions targeting SB are better tolerated by older adults than those that target PA, mainly because it is easier to re-allocate SB to standing or light activities than to allocate it to structured PA (Prince et al., 2014). Adherence to the intervention of 95.3% in this study supports that suggestion. The only participant in the IG who declined to continue, reported that they disliked the body-worn monitor. Retention among the control group was much lower at 52.9% (2 people lost the accelerometer and then declined to continue, six people lost interest and declined to continue). Poor retention in SB intervention studies with older adults is not unusual. Paw et al. (2006) reported an average dropout of 26% from three intervention groups and 39% dropout from the control group over a six-month period. The researchers did not use behaviour change or peer support as part of the intervention, and this could have affected retention among the intervention group. Harvey et al. (2018) reported 52% completion in a 14-week SB intervention using a transtheoretical model of behaviour change and real-time feedback. Participant retention in nineteen SB interventions with older adults published since 2006 has averaged 84%, but this figure includes three, single session interventions where retention was 100% (Gardiner et al., 2011; Fitzsimons et al., 2013; Lewis et al., 2016). Peer support may be an important aspect of participant retention. In a recent review, Lindsay Smith et al. (2017) found that social support was an important ingredient in PA interventions that sought to increase leisure time PA. Although no similar studies have investigated the influence of social support for SB reduction, the findings suggest that the social support element of the weekly group discussion in this intervention may have aided retention.

The BC strategy used in this study was derived from Michie's (2014) COM-B (capability, opportunity, motivation and behaviour) model. The strategy was also informed by Gardiner et al. (2016) who found that the 'most promising' mechanisms for SB interventions revolved around environmental restructuring, persuasion or education. The initial intervention presentation to IG participants in this study included elements of education, persuasion and training. It also engaged participants in self-monitoring discussions that included problem solving and restructuring the social and physical environment. The group were scheduled to meet each week to discuss changes made in the previous seven days, thereby enabling the social support element of the intervention. Although adherence to the weekly, fifteen-minute discussion among the IG was 100%, it is unclear whether any of this was influenced by the intervention or was simply down to the fact that the group were scheduled to meet at that time each week anyway. Participants reported that they were not interested in keeping a written record of SB change (5% completion over the intervention period) and preferred to discuss changes in the weekly group meeting. Suggestions made by participants at the meetings were noted and used to suggest alternatives to both purposeful and non-purposeful SB for the next week. For example, one participant reported decreased stiffness and back pain in the evening as a result of performing squats during TV advert breaks during the day. However, this activity was not replicated by other members and it only lasted for one week with the participant who reported it. Participants were supportive of standing to make telephone calls or standing during TV advertising breaks during the day and these were activities that the intervention groups agreed to try to make permanent additions to future behaviour. It became apparent by week 2 that changes to SB involving additional daily physical activity were not well supported by participants, who felt that their commitment to the community group activities constituted sufficient daily physical activity. However, the inclusion of daily tasks that would need to be undertaken regardless of the intervention e.g. household chores, cutting sticks for the fire, paying bills, using the upstairs bathroom instead of the downstairs bathroom, were well supported as mechanisms to break up sedentary time and remain cognitively active when at home in the afternoons. In general, participants were not supportive of activities they perceived as adding to the daily workload.

Participants did not arrive at the same time each week for the discussion. Meetings were due to take place at 11am each Monday for one group and at 6.30pm for the other (IG participants were sourced from two different community groups). However, participants would often arrive between 11 – 11.30 am or between 6.30 – 7 pm for the meeting, making group discussions and the sharing of ideas more difficult. Regardless of the reasons for attendance, the intervention aligned well with Michie's (2014) COM-B model. The intervention was low in burden for participants, which assisted with the 'capability' element of the model; the regular, weekly community group meeting assisted 'opportunity' and the social support of other group members assisted 'motivation'. The fact that the COM-B model used here also met the APEASE (affordability, practicability, effectiveness, acceptability, side-effects, equity) criteria assisted with the motivation and retention of IG participants. IG retention alone is a valuable outcome of this study, given the high rate of attrition by older adults from other SB interventions.

Mean, objectively-derived SB at baseline in this study was 9.4 $hrs.day^{-1}$. This tallied with findings by Harvey et al. (2015) who reported that older adults spent up to 9.4 hours (60-80% of their waking day) in SB. The IG in this study recorded an SB reduction of 22.9 $min.day^{-1}$ from baseline to T1 (against an SB increase of 20.1 $min.day^{-1}$ among the CG). This reduction was not statistically significant ($p>0.05$) between groups across the 6-week intervention and 4-week follow-up. However, it was similar in other SB interventions that used BC as the primary intervention tool. Fitzsimons et al. (2013) reported a 24 $min.day^{-1}$ reduction ($p<0.05$) after a 2-week face-to-face BC intervention and Barone-Gibbs (2017) reported a 25 $min.day^{-1}$ reduction after a 12-week telephone intervention, though this was not statistically significant.

Whether the SB reduction in this study could be considered clinically significant is unclear. There is strong cross-sectional evidence that SB is associated with physical function, morbidity and mortality in older populations ((Harvey et al., 2018; Sardinha, 2015) but there is no evidence to suggest a minimum or optimal SB reduction for clinical effects in a dose-response manner. However, the current body of evidence is suggestive of a dose-response relationship. For example, Rosenberg et al. (2016) found that older adults had a 21s increase in 400m walk time for every one hour increase in sedentary time while Dunlop et al. (2014) found that each additional hour spent sedentary was associated with a 50% increased risk of

ADL impairment. In Chapter 3 of this thesis, a 1 $hr.day^{-1}$ reduction in SB was associated with a 1 $kg.m^{-2}$ lower BMI. The associations between SB and health among older adults extend further than physical function. Keadle et al., (2015) reported that a decrease in television viewing of at least one hour (from over 5 $hr.day^{-1}$ to 3–4 $hr.day^{-1}$) was associated with a 15 % reduction in mortality risk (CI:0.80, 0.91) while Buman et al. (2014) reported that, for every 30 $min.day^{-1}$ of SB that was reallocated to LIPA, there was a 2–4% improvement in biomarkers (e.g. triglycerides, insulin, β-cell function). These findings suggest that a sustained reduction of even 1 $hr.day^{-1}$ in SB could confer significant clinical benefits to older adults, whether the reduction is substituted by MVPA or LIPA. In fact, Prince et al. (2014) suggest that per-minute clinical outcomes will continue to improve as energy expenditure increases from LIPA to MVPA.

The benefits of SB to physical function and health in older adults may depend, in part, on the functional ability of participants at baseline. Lower functioning participants can expect greater broad-spectrum improvements from increased daily energy expenditure than their higher functioning peers (Breda et al., 2017). Several researchers have reported a ceiling effect of functional improvement for people who are already highly functional. White et al., (2017) conducted a 12-week habit-based SB intervention and found that the intervention conferred no advantage when compared with the control group. The researchers reported that they failed to recruit the most sedentary and inactive members of the population (the intended recipients) and instead recruited more active older adults, thereby reducing the potential effectiveness of the intervention. A similar situation may have occurred in the present study.

Although SB decreased for the IG over the intervention period, it returned close to baseline levels at T2 (follow-up). The intervention period was relatively short and consequently, participants may not have had time to adjust to changed behaviour and persist with new habits. The high functional capacity of participants may also have been a factor here. It has been suggested that older adults who are already physically active, or who participate in PA can maintain or even increase daily SB and consider it a reward or a rest from their activities (Prince et al., 2014). Currently, little information is available on the intervention duration required to achieve an enduring reduction in SB, but researchers have conducted successful SB interventions with older adults in various durations from one week (Gardiner et al., 2011) to six months (Kallings et al., 2009). Unfortunately, most of the current crop of SB interventions have not included a follow-up assessment to check for BC maintenance.

The number and duration of sedentary bouts and number of breaks in sedentary time are also important to functional capacity for older adults. Sardinha et al. (2015) reported that fewer than seven breaks per hour in sedentary time during the day were associated with a two to five-fold increase in odds for impairment and dependence, independent of time spent in MVPA. In this study, the time spent each day in sedentary bouts >30 min decreased by 1.5% ($p>0.05$), time spent in sedentary bouts >60 min decreased by 8% ($p>0.05$) and sit-to-stand transitions showed no change. None of these were statistically significant however, given the fact that prolonged SB has been reported as detrimental to functional capacity, the reduction in SB bouts over 60 min could be viewed as a step in the right direction.

Dropout from this study was low for the IG (9.5%) but high for the CG (47%) and the study was underpowered (188 participants in total were required to achieve 80% power at α 0.05). The dropout rate for the control group was higher than that reported for similar studies.

White et al. (2017) lost only 8% of the intervention group and 6% of the control group during a twelve-week intervention. A review by King et al. (1998) reported a median loss of 17% of participants from 22 separate studies over a six-month period. Dropout among the IG in this study resulted from one participant who disliked the monitor and removed it. In the CG, two participants lost the monitors and then decided not to continue with the study. The other six participants who dropped out reported that they had lost interest in the study and declined to continue. An imputation analysis, using the mean value for each group, showed no change to within subject or between group effects for two of the reported SB variables, raising the possibility that higher subject retention may not have changed the effect of the BC intervention.

SB is likely to be replaced by some type of physical movement and therefore changes in SB could also be reflected in additional steps taken per day. The act of taking a step has been described as the most basic expression of human mobility (Tudor-Locke et al., 2011) and can be used to describe the continuum of physical activity from the most basic lower body movement in upright posture to high intensity exercise. Evidence suggests that a step count which includes 30min moderate-vigorous physical activity (MVPA) per day should total around 7,100 steps.day^{-1} for healthy older adults (Tudor-Locke et al., 2011). A rapid review of twenty-four SB interventions (using the activPAL) was conducted by Chan et al. (2017). The authors reported the highest recorded step count of any study in the review to be 8865 steps.day^{-1}. In this study, the intervention and control groups recorded 8431 steps.day^{-1} and 8818 steps.day^{-1} at T1, indicating a high-functioning cohort. IG participants in this study recorded a pre- to post-intervention increase of 281 steps.day^{-1} (3.5%) which was accompanied by a reduction in total objectively measured SB of 22.9 min.day^{-1} (4.1%), suggesting that SB may have been displaced by additional stepping activities. However, this change was not statistically significant. Tudor-Locke et al. (2011) report that 7000-10,000 steps per day is regarded as achievable for healthy adults aged 18-65 and there is no reason to suggest that healthy older adults in free living environments cannot be subject to the same guidelines.

Subjectively derived SB (via questionnaire) is frequently reported to underestimate sedentary time in older adults. Differences between objectively and subjectively derived measures have ranged from 3.6 $hr.day^{-1}$ (Gardiner et al., 2011) to 5.2 $hr.day^{-1}$ (Gennuso et al., 2015). In a review by Harvey et al., (2015) older adults reported sitting on average 5.3 $hr.day^{-1}$, which contrasted sharply with objectively derived measures showing an average sitting time of 9.4 $hr.day^{-1}$. In a systematic comparative validation, Chastin et al. (2018) suggests that self-report measures of sedentary time generally result in large bias, poor precision and low correlation with the activPAL accelerometer, with random error in excess of 2.5 $hr.day^{-1}$. In this study, SB reported from the questionnaire at baseline was 8.4 $hr.day^{-1}$, an average of 1 $hr.day^{-1}$ (9.4%) below that of the objective measurement. Although the disparity was low, it increased at T2, with a difference of 2 $hr.day^{-1}$ between objectively and subjectively derived measures. However, this was still considerably less than the differences reported in literature, indicating that the SBQ may have been more reliable for this population than some other subjective measurement tools. The Bland & Altman plot and subsequent regression analysis revealed some bias between measures, whereby the subjective tool (SBQ) was proportionately biased towards a lower SB. The activPAL was considered to be the reference value due to the higher precision of the device. However, for proportional bias to occur, the two measures should be recording the same phenomenon. As previously discussed, the activPAL may not be entirely accurate when recording SB in older adults who exhibit polycyclic sleeping patterns and long periods of supine inactivity during the day, that may or may not be classified by the device as time spent sleeping. Given that SB is defined as sitting, reclining or lying time with low energy expenditure while awake, this leads to the potential for misclassification of SB in this cohort, which in turn could lead to an interpretation of bias towards either the subjective or objective measurement, particularly as the bias demonstrated here was small.

The primary purpose of subjective SB measurement in this study was not simply to record sedentary time, but to gain insight into the context in which sedentary behaviour occurred. Gennuso et al. (2016) reports that patterns of SB among older adults are more important than total SB time because not all SB is harmful. SB can be described as either purposeful (engaging cognitive or social skills e.g. socialising, solving puzzles, reading) and therefore less harmful to overall health, or non-purposeful (e.g. watching television or other screen time) and therefore more harmful to the health of older adults. In this study, watching television (32.8%), transport (18.3%) and paperwork (12.7%) together constituted 63.8% of total sedentary time at baseline on weekdays, whereas watching television (35.9%), transport (18.6%) and reading (12.7%) constituted 67.25% of sedentary time at weekends. Reading at weekends appeared to displace time spent on paperwork during the week, with the other categories remaining constant. This finding is broadly in agreement with other studies investigating SB context. Gennuso (2016) found that watching the television, computer use and reading constituted most of an older adult's sedentary time whereas Gardiner et al., 2011 found that socialising took more time than computer use, with television watching as the greatest source of SB. The home environment is reported to be the source of most SB for older adults and, although the SBQ doesn't categorically ask about locations, almost all of the SB reported here could reasonably take place at home. Leask et al. (2015) found that approximately 70% of sedentary time occurred in the home and most of the non-purposeful SB took place during leisure time (49.2% of sedentary time), in the afternoon, when alone and often involved screen time.

Owen (2012) identified the home environment as the most likely, of four key domains, to be the source of most prolonged SB for older adults. This is therefore the domain where future BC interventions should focus with older adults.

5.6 Limitations

The validity and generalisability of the findings in this study need to be placed in the context of its limitations. The study was underpowered due to the dropout rate from the control group. In order to achieve the required power, 178 participants were needed but this number would need to have been greater to account for the percentage dropout experienced here. Even then, there may have been a large imbalance between results from the intervention and control groups at T2. A randomised crossover study may have improved retention of the control group since both groups would have received the intervention.

There were differences between participants at baseline and an ANCOVA showed a small effect for group for SB. This may have resulted from unsuccessful randomisation (this was performed at group level rather than individual level) and may have affected the inferences made from data collected throughout the study. The main data analysed here is taken from a complete case analysis. Although imputed data were also analysed, missing data may have further reduced the statistical power of this study and led to biased inferences and estimates.

There is little research to recommend the most effective BC strategy for use with older adults and the bulk of current literature applies to adults aged 18-65 years who tend to have a daily routine that is structured differently to older, retired adults. The strategy used in this study led to high participant retention among the intervention group but had little effect on SB reduction. The intervention may need to have been extended so that participants could form and maintain new, more permanent habits that included a more clinically relevant SB reduction.

The intended recipients of this intervention were older adults from across the spectrum of functional ability. However, the volunteers tended to be highly functional and socially active at baseline and may not have been motivated by the potential functional, health or social benefits associated with reduced SB.

Participants were asked not to make changes to normal behaviour or activity levels at baseline. However, McCambridge et al. (2014) suggest that 'consequences of research participation for behaviours being investigated do exist' and participants may have been subject to the Hawthorne effect at the three measurement points. Wearing the activPAL for seven days continuously may have had a reactive effect on participants' habitual daily activity and sedentary behaviours during the wear-period, thereby affecting the inferences made here. Although the intervention was conducted during the summer months, the weather was changeable and patterns of PA and SB are sensitive to environmental fluctuation among older adults who have less formal daily routines than younger, working age adults. All assessments for all groups were not conducted at the same time or on the same day, so environmental conditions could have affected activity levels and SB from week to week.

Research suggests that older adults have trouble with PA and SB questionnaires that require recall, even over the space of a week. This may have led to over- or underestimation of time spent in SB in the various categories in this study, thereby affecting the validity of the findings.

This study did not account for other determinants of health or physical function such as polypharmacy, psychological stress, sleep quality or diet. Therefore, any inferences made regarding the effect of SB on health should be considered in that context.

5.7 Conclusion

Older adults, particularly those for whom increased PA is difficult, may benefit from interventions that seek to reduce time spent in prolonged sitting or lying postures. The findings here suggest that BC interventions should target time spent in non-purposeful SB, (particularly screen time) that is conducted at home and when alone. The small reduction in SB found in this study may have proved more significant with a larger sample size (fully powered study) or with a longer intervention period. The highly functional nature of participants may have affected the participants' tendency to change behaviour and therefore, the effect of the intervention on SB reduction.

BC interventions should record SB objectively (for precision and accuracy) and subjectively (for context) so that reduced and/or displaced SB can become contextually less harmful to older adults. Self-reported quantities of SB should be viewed with caution, in conjunction with SB context and should be reported alongside objective measures. However, self-reported SB is useful to establish context for the behaviour. Accelerometers that incorporate an inclinometer should be used to improve the reliability and validity of SB measurement.

The ideal or optimum dose of SB reduction needed for clinical effect is still unknown but there is an increasing body of evidence to suggest that even 1 $hr.day^{-1}$ of SB substituted for LIPA can confer functional and/or health benefits on older adults. However, this may depend on the individual, with SB reduction conferring greater benefit on those people with lower baseline physical function or health. The optimum intervention to use with older adults is still unclear as heterogeneity in BCTs within the literature is high. However, the findings from this study suggest that low burden interventions conducted in a community group setting, where participants can avail of social support from peers, may encourage higher levels of retention and may help to reduce problems with subsequent underpowering.

Chapter 6

General Conclusions

6 General Conclusions

6.1 Summary of Findings

The aim of this thesis was to investigate the relative impact of SB and PA on the physical function of older adults, and to develop a practical, easy to administer intervention that could be used to reduce SB in this cohort.

The literature review suggests that the relationship between PA, physical function and falls risk among older adults is well established. However, the relationship between SB and health outcomes among older adults is less well known, and there is a lack of cross-sectional and intervention data in this area, particularly regarding physical function. SB, which was previously considered to be simply a lack of PA, is now considered to be a separate construct that independently affects the physical function, quality of life and overall health of older adults. Studies have been conducted with children, adults of working age and older adults to establish associations between SB, morbidity and mortality. However, older adults experience geriatric syndromes that do not affect other sections of the population. These include balance impairment and falls risk, impaired ADLs and increased incidence of isolation, depression and cognitive impairment, all of which are associated with SB. Cross sectional data suggests that older adults who sit less experience lower levels of morbidity and increased levels of healthy life expectancy. However, the effect of SB reduction interventions on geriatric syndromes is not known. PA interventions are not well tolerated by older adults and recruitment for SB reduction interventions may be more successful. The reduction or displacement of total SB is important for all sections of the population. However, a shift from non-purposeful SB (in the form of screen time) to purposeful SB (in the form of social interaction, problem solving or other cognitive engagement) may be important in delaying the onset of age-related conditions in older adults.

Chapter Two of the thesis addressed Objective 1: which, of SB or PA, had the greatest association with physical impairment among community dwelling older adults. There is a well-established link between PA, physical function and overall health in older adults. However, at the time of writing, there were no comparative studies that examined the relative effect of PA and SB on physical function or sought to establish whether PA and SB were associated differently with physical function in older adults.

By definition, community dwelling older adults experience a level of physical function that enables them to live independently. However, the range of function that is evident among this cohort is considerable. It ranges from adults who live completely independently in their own homes and use their own transport, to those who are supported or who are close to dependent/ institutional living. The older adults who volunteered for the cross-sectional study in this thesis were community dwelling and typically highly functional. Therefore, they may not have been representative of all community dwelling older adults. They were also unlikely to be representative of the wider population of older adults, given the number of people who live in supported or institutional care. Therefore, it should be noted that the results and inferences made from this study can only be applied to a highly functional cohort of community dwelling older adults and not necessarily to older adults across the functional spectrum.

Recruitment for the cross-sectional study was difficult and acceptance or rejection of the opportunity to participate by one community group leader/ administrator tended to result in the other members following suit. Lindsay Smith et al. (2017) report that social support is important to older adults and people with greater social support for PA are more likely to participate. This may have explained the reluctance of some groups to participate in this study. Also, anecdotally, it was observed that active ageing groups were more likely to volunteer for the study than those in less active older adults' outreach groups. To form a complete picture, a cross-sectional study needs a broad range of volunteers from across the spectrum of physical function. This did not happen here, thereby affecting the inferences that could be made from the data.

A problem associated with older adults' functional assessments is that some of the commonly used assessments have a ceiling effect for highly functional participants. For example, the Berg Balance Scale (Berg, 1992) was designed to assess balance impairment and falls risk. However, the scale that is used to score the assessment is not continuous. Therefore, if a participant is highly functional and does not experience balance impairment, it may be difficult to determine smaller differences or changes in balance over time.

The findings from the cross-sectional study suggested that physical function was more strongly associated with PA levels than SB. However, when total sitting/ lying time (including sleeping time) was used in the analysis, there was little difference in the association. Time spent sleeping is currently excluded from the definition of SB. However, sleeping also involves very low energy expenditure in a sitting or lying position. Therefore, total sitting/ lying time that includes sleep may be a more significant predictor of functional impairment among older adults than total sitting/ lying time while awake. The findings suggest that future research studies should not restrict the analysis of the SB/ physical function relationship in older adults solely to the current (waking time) definition.

The most recent consensus definition states that sedentary behaviour is ‘time spent sitting, reclining and lying during waking hours, accompanied by energy expenditure below 1.5 METs’ (SBRN, 2017). However, Barone Gibbs & Kline (2018) report that sleep-related behaviours (wakefulness after sleep onset, sleep onset latency, night awakenings) should not be classified as sedentary behaviour since they are part of the normal sleep/wake cycle and should not be regarded as an intervention target (Figure 6.1). They recommend diaries that report all aspects of time related to bedtime and waking time so researchers can extract wakefulness periods from the data. Older adults experience polycyclic sleeping patterns that do not divide sleep and wakefulness into day and night. A diary would help to separate SB from sleep but could confer a considerable additional burden on participants. However, this is a ‘grey’ area that needs to be resolved so that SB can be accurately and reliably monitored and recorded (figure 6.1).

	Sedentary behavior	Sleep-related behavior	Sleep behavior
Definition	Waking behavior where subject is engaged in an activity while in bed	Waking behavior where subject is attempting to fall asleep or return to sleep	A reversible behavioral state involving altered consciousness and reduced responsivity to external stimuli, usually occurring with closed eyes, behavioral inactivity, and while recumbent
Examples	Reading, watching television, using a smart phone, tablet, or computer while in bed prior to going to sleep, in the middle of the night, or in the morning prior to getting out of bed	Lying in bed while trying to fall asleep at night (sleep onset latency [SOL]), during night awakenings (wake after sleep onset [WASO]), or in the morning following final awakening prior to starting any activities (wakefulness after sleep offset [WASF])	

Figure 6.1 Clarification of in-bed behaviours: sedentary, sleep-related and sleep (Barone Gibbs & Cline, 2018)

Chapter three of the thesis addressed Objective 2, which was to conduct a systematic review of SB interventions among older adults. This was done to determine which SB intervention mechanisms had previously been successful and why, and to inform the design of a future SB intervention. SB research with older adults is still in its infancy. Interventions conducted up to May 2017 were generally low quality, pilot or prospective studies and many were single group, uncontrolled studies using samples of convenience. Most of the Interventions up to 2019 were still small-scale trials exploring various BCTs and intervention durations. To date there are no large scale SB-specific RCTs with older adults.

The literature demonstrated that the causes of SB and mechanisms for intervention with older, retired adults were different to those of working age adults and it highlighted a lack of high-quality research. Studies designed to displace non-purposeful SB with either purposeful SB or with LIPA achieved more long-term success than those designed to replace SB with MVPA, and PA levels did not always increase after SB interventions. Multi-component interventions that treated SB and PA separately did achieve some success, suggesting that future interventions should also treat the two constructs separately. The literature highlighted the importance of behaviour change in SB reduction and most interventions were based around models of either social cognitive theory or self-determination theory. However, heterogeneity among studies was high and best practice in SB reduction among older adults could not be determined. Intervention studies can be used to provide information on cause and effect or clinical significance. However, none of the studies in this review indicated a dose-response relationship between physical function and SB, so it was not possible to determine whether physical function would improve if SB was reduced or displaced. Previous large-scale, cross-sectional studies have demonstrated associations between SB and functional impairment, thereby suggesting that a dose-response relationship may exist. Also, older adults are reported to tolerate interventions that seek to displace SB better than those that seek to increase PA. Therefore, achieving a clinically meaningful improvement in physical function via SB reduction is a worthwhile goal and should be investigated further.

Chapter 4 & 5 addressed Objective three: to use the findings from the literature review to develop and deliver a SB reduction intervention to older adults. The intervention needed to be practical, easy to administer and tolerable to a broad range of participants. Findings from the systematic review, and from studies conducted subsequent to 2017, could not be used to determine the most appropriate mechanism for SB reduction because heterogeneity among research designs was high. Studies used a range of BC interventions based on: empowerment theory (Chang et al., 2013), social cognitive and behavioural choice theories (Gardiner et al., 2011; Mutrie et al., 2012; Roberts et al., 2019), self-determination theory (Lewis et al., 2016), the habit formation model (Matei, 2015; Matson et al., 2018) and self-regulation theory (Kotlyn et al., 2019). In 2013, Michie et al. produced a taxonomy of BCTs from the integration of nineteen of the most commonly used theories of behaviour. Prior to this, in 2011, the authors introduced the BCW (Behaviour Change Wheel) which was a model for the design of BC interventions. The BCW, in conjunction with recommendations on successful intervention functions by Gardiner (2016) and successful BCTs used by researchers from the systematic review were then used to develop the intervention in this thesis. The findings showed no significance for group x time. However, a small increase in total steps pre- to post-intervention of 281 steps.day^{-1} (3.5%) was accompanied by a reduction in total objectively measured SB of 22.9 min.day^{-1} (4.05%), suggesting that SB may have been displaced by additional stepping activities. Participant dropout within the control group was 41% and the study was underpowered. A randomised, crossover trial may have encouraged more of the control group participants to remain in the study since they would also have received the intervention. As with the cross-sectional study, the participants in the intervention study were typically highly functional community dwellers and were active participants in community groups that regularly required cognitively or physically demanding tasks to be undertaken by members. Therefore, they were unlikely to be representative of the wider population of older adults and the results and inferences made from this study may not be applicable to older adults across the functional spectrum.

The Hawthorne effect (behaviour modification in response to observation) may have been a factor in the findings from both the cross-sectional and intervention studies. McCambridge et al. (2014) suggested that the effect is highly contingent on task and context and may be more prevalent in short term studies. The Hawthorne effect may have caused behaviour modification among the participants in this study. However, both groups were assessed in the same way at each timepoint which may have mitigated the overall impact of the effect on the results. Also, although the control group did not receive the BC intervention, the use of the accelerometers to measure SB and PA may themselves have influenced PA and SB patterns and habits. Roberts et al (2019) found that older participants using a body worn activity monitor recorded 48 $min.wk^{-1}$ less SB during a 12-week exercise intervention than people who completed the intervention with no activity monitors.

The potential effect of seasonal weather and geographical region on PA, SB and physical function was not addressed in this thesis. Environment, season and weather can affect activity patterns and snapshot assessments of SB and PA taken over seven days (such as those conducted in this thesis) with body worn monitors does not take this into account. However, the impact of weather and season may be greater on levels of PA than for SB. Hagstromer et al., (2014) found a significant trend for seasonal MVPA but not for SB among older adults in

Sweden. Yerrakalva et al. (2019) found that older adults were habitual in overall SB time and SB bouts over seven days and displayed little compensation for day to day changes in PA.

Although SB reduction interventions may be better tolerated than increased PA, recommendations to increase PA among older adults should remain strong. MVPA can attenuate the negative health consequences of SB (Biddle et al., 2019) and has long been associated with improved cardiovascular and metabolic health. They may be separate constructs, but a considerable body of cross-sectional, cohort and experimental evidence has demonstrated similarities in the physical health consequences of low PA and sedentary lifestyles. Both prolonged sitting and low levels of PA are associated with higher postprandial glucose and insulin levels (Dempsey et al., 2018), and regular standing breaks over 10 min in duration may be enough to improve these cardiometabolic biomarkers in this cohort. Unfortunately, older adults are the most inactive section of society and need to be informed that both non-purposeful SB reduction and increased PA need to be addressed together.

Recent evidence is moving towards a more systematic approach to the characterisation of SB, one that considers both the behaviour context type (Hallgren et al., 2019), to determine both the physiological and psychological impact of SB. This thesis provides a commentary mainly on the physical/physiological consequences of prolonged SB. However, evidence suggests a strong association between mental health outcomes and SB, such that regular interruption of sitting during leisure time may reduce the odds of experiencing depressive symptoms (Hallgren et al., 2020). Mentally passive (non-purposeful) SB is reported to have a greater association with poor mental health than mentally active (purposeful) SB (Hallgren, 2019). This differentiation is becoming more important when investigating the overall health impact of SB on older adults. Compernolle (2020) suggests that physical capacity, disability, reduced mobility problems and tiredness reinforce SB among older adults and that automatic and reflective motivations play a significant role in the subsequent reinforcement of these behaviours. A shift towards more productive and cognitively purposeful SB, particularly among those for whom physical mobility is difficult, may benefit cognitive and social health and provide some protection against cognitive decline. However, current research cannot yet tell us whether a shift towards purposeful SB is beneficial to overall health or to physical function.

Selection bias may have been a factor in these studies, given the fact that adults in active ageing groups were more likely to volunteer for the studies than people in less active community outreach groups. There are still some areas to be sorted with SB for older adults e.g. definitions and sleeping time etc. Reliability and validity of self-report needs to improve. Additional data also needs to determine the effect of environment, season or weather on SB in this population.

6.2 Strengths and Limitations

The strengths of the cross-sectional study lie mainly with the measurement tools used to assess physical function, SB and PA. The Berg Balance Scale (Berg, 1992) and the Seniors Fitness Test (Rickli & Jones 1999) are commonly used clinical assessments of function and balance for older adults. There is little published research to distinguish between health indicators that are affected by PA and those affected by SB. This study was the first to directly compare PA and SB with physical function in community dwelling older adults.

The limitations of this study, and indeed the thesis, include the exploratory nature of the studies, the functional status of participants at baseline and the ceiling effect of some assessments. By definition, a cross-sectional study should sample participants from across the functional range. Unfortunately, this was not the case here and participants tended to be highly functional, thereby limiting the scope of the inferences. A large number of outcomes variables were used to explore the relationships between PA, SB and physical function raising the potential for artefact within the findings. In addition, the Berg Balance assessment is not measured on a continuous scale and therefore has a ceiling effect for participants who are highly functional.

A strength of the systematic review was the finding that successful SB interventions with older adults tended to use BC strategies and treated SB as a separate construct to PA. The review suggested that social support was a key ingredient to behaviour change with older adults and demonstrated that changed behaviour could be maintained post-intervention.

A limitation of the review was the high level of heterogeneity among study designs and measurement techniques. This meant that a model of best practice was not available for the intervention design and a meta-analysis on the available data could not be conducted.

A strength of the intervention study was the use of both objective and subjective measurement tools to record SB. Most previous interventions have used either questionnaires alone to record SB (which can be inaccurate by 2.5 – 4.5 $hrs.day^{-1}$) or have used accelerometers (which cannot provide sedentary context). The findings from this study add to the body of evidence suggesting that older adults in Ireland tend to engage in non-purposeful SB when alone, at home and in the afternoons. Geographical dispersion for this study, and the cross-sectional study, were good (data was gathered over a distance of approximately 120 miles between Northern Ireland and the Republic of Ireland) which strengthens the geographical generalisability of the findings. The study provided evidence that social support was important to the success of the intervention. This may have been partly responsible for another strength of this study i.e. good recruitment of males. Gender is an important determinant of health behaviour, particularly when males are more likely to engage in unhealthy or high risk behaviours like alcohol consumption, smoking and physical inactivity (Ryan et al., 2019). Intervention studies tend to comprise around 20% males, making the relevance of inferences made from this type of study difficult to apply to the whole population (Ryan et al., 2019). The community groups recruited for this study included two 'Men's Sheds', an association of community spaces for men that was designed to help reduce loneliness and isolation among this section of the population. The sense of community in these groups and the requirement for members to undertake long-term, ongoing craft projects, helped with regular attendance at the weekly meetings It also helped with participant retention, since this cohort comprised the intervention group who were required to meet the researcher each week. The other group (CG) that participated were a choir (comprised exclusively of retired older adults) who met weekly and performed regularly in the community. Retention among this group here was not as high, but the members were not given the intervention, were not required to meet with the researcher each week and were not asked to exchange ideas or keep a SB diary.

Limitations of this study included the dropout of participants from the control group and the baseline characteristics of participants. Participant retention among the control group was 53%. According to the sample size calculations which required 188 participants for a fully powered study, this trial was insufficiently powered to detect statistically significant changes in SB. In addition, although this was a randomised controlled trial, the participants who volunteered were recruited from community groups and were randomised at the level of the group rather than the individual. According to Hemming et al. (2011) the variance of the difference to be detected in cluster randomisation requires a 'variance inflation factor' to be included in the calculation, which would have further increased the number of participants required for a fully powered RCT. Cluster randomisation may also have resulted in selection bias, given that all the intervention group were male, whereas half the control group were female. Active ageing groups were more likely to volunteer for the studies than older adults in less active outreach groups. The BC strategy used here may also function differently when used with a cross-section of community dwelling older adults that includes functionally impaired participants.

6.3 Recommendations for Future Research

Tests of physical function with older adults tend to be designed for, and administered at, the expected level of function within the population studied. Leung et al. (2017) found that older adults who spent more time in SB performed more poorly on tests of balance and physical function. They also found that older adults in assisted care facilities were 87% more sedentary than their community dwelling counterparts. The older adults who volunteered for these studies were highly functional and community dwelling and may not have been representative of the wider population. Although it is difficult to recruit older adults from across the spectrum of physical function, future SB interventions need to investigate whether the health benefits conferred by reduced SB are greater for those who are more functionally impaired.

High quality RCTs are needed to establish whether a dose-response relationship exists between SB, physical function and health. Cross-sectional and cohort evidence suggests that a relationship does exist and that the benefits of SB reduction may be greater for those who are functionally or health impaired. However, SB interventions with older adults are still in early stages and this relationship has not yet been established. Investigations should extend to an examination of the effect of SB bout reduction and determining the different effects on health and physical function of substituting SB with additional standing, LIPA and MVPA.

Given the increasing prevalence of SB among older adults, future studies should focus on developing low cost, low burden, practical BC interventions that can be delivered in a wide range of community settings. BC interventions need to be effective in modifying behaviour, but the changed behaviour needs to be maintained for a health benefit to become evident. Therefore, SB intervention studies should include extended follow-up periods to assess the efficacy of the intervention and the longer-term effect. Post-intervention focus groups may also benefit the evaluation process.

Studies are also needed to address problems with SB measurement in older adults. Although accelerometers can provide precise data, objective SB measurement accuracy can be difficult with older adults because sleep and awake times cannot be time stamped. Questionnaires are currently used to contextualise SB, but they require recall, and this can be problem for older adults. The used of daily PA/ SB diaries have been proposed but these add to participant burden. Older adults' polycyclic sleeping patterns have uncovered a 'grey area' that does not yet distinguish between sleep-related behaviours and sleeping. Sleep is important to overall physical and mental health and function, but it also adds to overall time spent sitting or lying and may be a factor in functional decline with ageing. Also, although SB involves very low energy expenditure, it may not always be harmful to older adults' health (Chastin et al., 2018) so we need accurate contextual data to distinguish between SB that is harmful to older adults and SB that is not.

6.4 Conclusion

This thesis was designed to determine the effect of SB and PA on physical function in community dwelling older adults and to intervene to reduce SB in this cohort. This research area is still in its infancy and heterogeneity in study design is high. However, strong evidence suggests that prolonged SB has negative health and functional consequences for older adults. Total SB should be reduced but particular attention should be paid to breaking longer bouts of SB and displacing non-purposeful SB with either purposeful behaviours or with PA. The findings of this thesis that contribute to this field of research are:

i. Although most national physical activity guidelines tend to promote increased MVPA for its protective effect on health, total PA (combined LIPA, MVPA and VPA) may be a more useful indicator of physical functional status for older adults. The cross-sectional study found that physical function can vary significantly in accordance with total PA among independent community dwellers. Consequently, researchers should be careful to match the sensitivity and range of assessments completed to the expected physical functional ability of participants.

ii. Until the accuracy of measurement techniques improves, investigations into SB and physical function among older adults should broaden to include total time spent sitting/lying/sleeping. The cross-sectional study in chapter 2 found that sitting/lying/sleeping may have a broader influence on physical functional status than

SB alone. There may be two main reasons for this. Firstly, the current definition of sedentary behaviour accounts for very low energy expenditure during waking time spent sitting, reclining and lying but, under normal conditions, the nature of physical functional decline may not change according to whether or not an individual is asleep. Also, polycyclic sleeping patterns, long periods of supine inactivity during the day and poor recall make the accurate measurement of SB difficult with older adults, even when using objective measurement techniques that demonstrate high levels of precision.

iii. Chapters 3 and 5 demonstrated that behaviour change strategies are an important ingredient in the development of SB reduction/ displacement interventions for older adults. Future investigations into SB among older adults should focus on behaviour change, particularly related to displacing non-purposeful sedentary time that tends to occur in the afternoons, when at home and when alone. Ideally, intervention designs should incorporate BCTs that encourage SB reduction and increased PA. However, SB and PA are separate, but linked, constructs and BCTs should be designed to treat each one separately. The BCW provides a systematic and structured mechanism for designing SB interventions for older adults. The influence of peers and group support are useful tools to encourage retention among participants in BC interventions.

References

Ajzen, I. (1991) The Theory of Planned Behaviour. *Organisational behaviour and Human Decision Processes*, 50, 179-211.

Arking, R. (2006) *The biology of ageing: observations and principles*. Oxford University Press, Oxford.

Atkin, A.J., Gorely, T., Clemes, S.A., Yates, T., Edwardson, C., Brage, S., Salmon, J., Marshall, S.J. and Biddle, S.J.H. (2012) Methods of Measurement in Epidemiology: Sedentary Behaviour. *International Journal of Epidemiology*, 41:1460-1471.

Aunger J.A., Doody P. and Greig C.A. (2018) Interventions targeting sedentary behavior in non-working older adults: a systematic review. *Maturitas*, 116: 89-99.

Ballegooijen, A.J., van der Ploeg, H.P. and Visser, M (2019) Daily sedentary time and physical activity as assessed by accelerometry and their correlates in older adults. *European Review of Aging and Physical Activity* 16:3.

Bandura, A. (1986) *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice Hall.

Bangsbo J, Blackwell J, Boraxbekk C*, et al*. (2019) Copenhagen Consensus statement 2019: physical activity and ageing. *British Journal of Sports Medicine* 2019;**53:**856-858.

Barnett I., van Sluijs E., Ogilvie D. and Wareham N.J. (2014) Changes in household, transport and recreational physical activity and television viewing time across the transition to retirement: longitudinal evidence from the EPIC-Norfolk cohort. *J Epidemiol Community Health* 68(8):747-53.

Barone Gibbs, B., Brach, J., Byard, T., Creasy, S., Kelliann, K.D., McCoy, S., Peluso, A., Rogers, R.J., Rupp, K. and Jakicic, J.M. (2017) Reducing Sedentary Behavior Versus Increasing Moderate-to-Vigorous Intensity Activity in Older Adults: A 12-Week Randomised, Clinical Trial. *Journal of Ageing and Health* 29(2) 247-267.

Bastone A.C., Ferriolli E., Pfrimer K., Moreira, B., Mata Diz, J. B., Domingues Dias, J.M. and Dias, R.C. (2019) Energy Expenditure in Older Adults Who Are Frail: A Doubly Labelled Water Study. *J Geriatric Physical Therapy*, 42(3):E135-E141.

Bauman A., Ainsworth B.E., Sallis J.F., Hagströmer M., Craig C.L., Bull F.C., Pratt M., Venugopal K., Chau J. and Sjöström M. (2011) The Descriptive Epidemiology of Sitting. A 20-Country comparison using the International Physical Activity questionnaire (IPAQ). *American Journal of Preventative Medicine* 41(2):228-35.

Bayán-Bravo, A. Pérez-Tasigchana, R.F., López-García, E., Martínez-Gómez, D., Rodríguez-Artalejo, F. and Guallar-Castillón, P. (2019) The association of major patterns of physical activity, sedentary behavior and sleeping with mortality in older adults, *Journal of Sports Sciences,* 37:4, 424-433.

Berg K., Wood-Dauphinee S., Williams J.I., Maki B (1992) Measuring balance in the elderly: validation of an instrument. *Canadian Journal of Public Health*, July/August supplement 2:S7-11.

Biddle, S.J.H., Bennie, J.A., De Cocke,r K., Dunstan, D., Gardiner, P.A., Healy, G.N., Lynch, B., Owen, N., Brakenridge, C., Brown, W., Buman, M., Clark, B., Dohrn, I.M., Duncan, M., Gilson, N., Kolbe-Alexander, T., Pavey, T., Reid, N., Vandelanotte, C., Vergeer, I. and Vincent, G.E. (2019) Controversies in the Science of Sedentary Behaviour and Health: Insights, Perspectives and Future directions from the 2018 Queensland Sedentary Behaviour Think Tank. *Int J Environ Res Public Health*. 16(23):4762.

Biswas, A., Oh, P.I., Faulkner, G.E., Bajaj, R.R., Silver, M.A., Mitchell M.S. and Alter, D.A (2015) Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Annals of Internal Medicine*, 162:123-32.

Blair S.N., Kohl H.W., Paffenbarger R.S., Clark D.G., Cooper K.H. and Gibbons L.W. (1989) Physical Fitness and All-Cause Mortality: A Prospective Study of Healthy Men and Women. *Journal of the American Medical Association*, 262(17):2395–2401.

Blair, S., Kohl, H.W., Barlow, C.E., Paffenbarger, R.S., Gibbons, L.W. and Macera, C.A. (1995) 'Changes in physical fitness and all-cause mortality, a prospective study of healthy and unhealthy men', *Journal of the American Medical Association* 273: 1093-1098.

Boberska, M., Szczuka, Z., Kruk, M., Knoll, N., Keller, J., Holh, D.H., and Luszczynska, A. (2018) Sedentary behaviours and health-related quality of life. A systematic review and meta-analysis, *Health Psychology Review*, 12:2, 195-210.

Booth F.W., Laye M.J., Roberts M.D. (2011) Lifetime sedentary living accelerates some aspects of secondary aging. Journal of Applied Physiology, 111(5):1497-504.

Bowling, C. B., Booth, J. N., Gutiérrez, O. M., Kurella Tamura, M., Huang, L., Kilgore, M., Muntner, P. (2014). Nondisease-specific problems and all-cause mortality among older adults with CKD: the REGARDS Study. *Clinical journal of the American Society of Nephrology*, *9*(10), 1737–1745.

Bravata, D.M., Smith-Spangler, C., Sundaram, V., Gienger, A.L., Lin, N., Lewis, R., Stave, C.D., Olkin, I. and Sirard, J.R. (2007) Using Pedometers to Increase Physical Activity and Improve Health: A Systematic Review. *Journal of the American Medical Association,*298(19):2296–2304.

Brazier, J.E., Harper, R., Jones, N.M., O'Cathain, A., Thomas, K.J., Usherwood, T. and Westlake, L. (1992) Validating the SF-36 health survey questionnaire: new outcome measure for primary care, *British Medical Journal*, 305:160.

Brown, J.C., Harhay, M. and Harhay, M. (2016) Sarcopenia and mortality among a population-based sample of community dwelling older adults. *Journal of Cachexia*, *Sarcopenia and Muscle*, 7(3) 290-298.

Buman, M.P., Winkler, E.A., Kurka, J.M., (2006) Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. *American Journal of Epidemiology*, 179:323–334.

Burke, L., Lee, A.H., Jancey, J., Xiang, L., Kerr, D.,A., Howat, P.A., Hills, A.P. and Anderson, A.S. (2013) Physical activity and nutrition behavioural outcomes of a home-based intervention program for seniors: a randomised controlled trial. *International Journal of Behavioural Nutrition and Physical Activity* 10:14.

Burke, L., Jancey, J., Howat, P.A., Lee, A.H., Kerr, D.A., Shilton, T., Hills, A.P. and Anderson, A.S. (2010) Physical activity and nutrition program for seniors (PANS): protocol of a randomised controlled trial. *BMC Public Health* 10:751.

Buskirk, E.R. and Hodgson, J.L. (1987) Age and aerobic power: The rate of change in men and women. *Federation Proceedings*, 46, 1824-1829.

Campbell M., McKenzie J.E., Sowden A., Katikireddi Srinivasa, V., Brennan S. E., Ellis, S., Hartmann-Boyce, J., Ryan, R., Sheppard, S., Thomas, J., Welch, V. and Thompson, H. (2020) al. Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline *British Medical Journal*; 368 :l6890.

Cane, J., O’Connor, D. & Michie, S. (2012) Validation of the theoretical domains framework for use in behaviour change and implementation research. *Implementation Science* **7,** 37.

Carey, D. and Lafoy, M. (2005) Hospitalisations Due to Falls in Older Persons. *Irish Medical Journal,* 98(6):179-181.

Carey, K.B., Scott-Sheldon, L.A., Elliott, J.C., Garey, L. and Carey M.P. (2012) Face-to-face versus computer-delivered alcohol interventions for college drinkers: a meta-analytic review, to 2010. Clinical Psychology Review 32(8):690-703.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports (Washington D.C., 1974),* 100(2), 126–31.

Catalan-Matamoros, D.C., Gomez-Conesa., Stubbs, B. and Vancampfort, D. (2016) Exercise improves depressive symptoms in older adults: An umbrella review of systematic reviews and meta-analyses. *Psychiatry Research*, 244:202-209.

Chan C.S., Slaughter S.E., Jones C.A., Ickert C. and Wagg A.S. (2017) Measuring Activity Performance of Older Adults Using the activPAL: A Rapid Review. *Healthcare (Basel)*, 5(4):94.

Chang, A.K., Fritschi, C. and Kim, M.J. (2013) Sedentary Behaviour, Physical Activity, and Psychological Health of Korean Older Adults with Hypertension. Effect of an Empowerment Intervention. *Research in Gerontological Nursing* 6:2 p81-88.

Chastin SFM, Schwarz U, Skelton DA (2013) Development of a Consensus Taxonomy of Sedentary Behaviors (SIT): Report of Delphi Round 1. PLoS ONE 8(12): e82313.

Chastin SFM, Schwarz U, Skelton DA (2014) Correction: Development of a Consensus Taxonomy of Sedentary Behaviors (SIT): Report of Delphi Round 1. PLoS ONE 9(1): 10.137

Chastin, S.F.M., Culhane, B., Dall, P.M. (2014) Questionnaire sitting time (IPAQ) compared to objective measurement via inclinometry (activPal). *Physiological Measurement* 35(11):2319-28.

Chastin S.F.M, Fitzpatrick N., Andrews M., DiCroce N. (2014) Determinants of sedentary behavior, motivation, barriers and strategies to reduce sitting time in older women: a qualitative investigation. *Int J Environ Res Public Health*, 11(1):773-91.

Chastin, S.F.M., Buck, C., Freiberger, E., Murphy, M., Brug, J., Cardon, G., O'Donoghue, G., Pigeot, I. and Oppert, J-M. (2015) Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study, *International Journal of Behavioural Nutrition and Physical Activity*, 12:127.

Chastin S.F.M, De Craemer M., Lien N., Bernaards C., Buck C., Oppert J.M., Nazare J.A., Lakerveld J., O'Donoghue G., Holdsworth M., Owen N., Brug J. and Cardon G (2016) DEDIPAC consortium, expert working group and consensus panel. The SOS-framework (Systems of Sedentary behaviours): an international transdisciplinary consensus framework for the study of determinants, research priorities and policy on sedentary behaviour across the life course: a DEDIPAC-study. *International Journal of Behavioural Nutrition and Physical Activity*, 13:83.

Chastin S.F.M., De Craemer M., De Cocker K., Powell, L. Van Cauwenberg, J. Dall, P., Hamer, M. and Stamatakis, E. (2019) How does light-intensity physical activity associated with adult cardiometabolic health and mortality? Systematic review with meta-analysis of experimental and observational studies. British Journal of Sports Medicine 53(6):370-376.

Chastin S.F.M., Gardiner P.A., Ashe M.C., Harvey J.A., Leask C.F., Balogun S., Helbostad J.L. and Skelton D.A. (2017) Interventions for reducing sedentary behaviour in community-dwelling older adults. *Cochrane Database of Systematic Reviews*, Issue 9. Art. No.: CD012784.

Chastin S.F.M., Dontje M.L., Skelton D.A., Čukić I., Shaw R.J., Gill J.M.R., Greig C.A., Gale C.R., Deary I.J., Der G. and Dall P.M. (2018) Seniors USP team. Systematic comparative validation of self-report measures of sedentary time against an objective measure of postural sitting (activPAL). *International Journal of Behavioural Nutrition and Physical Activity*, 26;15(1):21.

Cherubini, A., Bernabei, R. and Lattanzio, F. (2010) Moving Against Frailty: does physical activity matter? *Biogerentology* 11:537-545.

Chin A Paw, M.J.M., van Poppel, M.N.M., van Mechelen, W. (2006) Effects of resistance and functional skills training on habitual activity and constipation among older adults living in long-term care facilities: a randomised controlled trial. *BMC Geriatrics*, 6:9.

Clegg, A., Young, J., ILiffe, S., Rikkert, M.O. and Rockwood, K. (2013) Frailty in Elderly People. *Lancet* 381: 752-762.

Compernolle, S., De Cocker, K., Cardon, G., De Bourdeaudhuij, I., Van Dyck, D., and Heyn, P. C. (2019) "Older Adults' Perceptions of Sedentary Behavior: A Systematic Review and Thematic Synthesis of Qualitative Studies" *The Gerontologist* 1758-5341.

Compher, C., Frankenfield, D., Keim, N., Roth-Yousey, L. (2006) Evidence Analysis Working Group. Best Practice Methods to Apply to Measurement of Resting Metabolic Rate in Adults: A Systematic Review. *Journal of the American Dietetic Association*, 106(6):881-903.

Cook J. (2011) The socioeconomic contribution of older people in the UK. Working Older People, 15(4):141–6 Available at: https://www.emerald.com/insight/content/doi/10.1108/13663661111191257/full/html. Accessed 27/11/2019.

Copeland J.L., Ashe M.C., Biddle S.J., Brown W.J., Buman M.P., Chastin S., Gardiner P.A., Inoue S., Jefferis B.J., Oka K., Owen N., Sardinha .LB., Skelton D.A., Sugiyama T. and Dogra S. (2017) Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. *British Journal of Sports Medicine.*, 51(21):1539.

Copeland, J. (2019) Sedentary time in older adults: Sitting is not the new smoking. *Kinesiology Review* (8) 70-76.

Cunningham, C. & O'Sullivan, R. (2019) Physical activity and older adults: An overview of guidelines, trends, policies and frameworks. *Institute of Public Health in Ireland*. Dublin/ Belfast.

Dall, P.M., Coulter, E.H., Fitzsmons, C.F., Skelton, D.A. and Chastin S.F.M. (2018) Taxonomy of Self-reported Sedentary behaviour Tools (TASST) framework for development, comparison and evaluation of self-report tools: content analysis and systematic review. *British Medical Journal Open* 7(4) e013844.

Davies, P., Walker, A. E., & Grimshaw, J. (2010). A systematic review of the use of theory in the design and implementation strategies and interpretation of the results of rigorous evaluations. *Implementation Science*, 5, 1–6.

Dempsey, P.C.; Larsen, R.N.; Winkler, E.A.H.; Owen, N.; Kingwell, B.A.; Dunstan, D.W. Prolonged uninterrupted sitting elevates postprandial hyperglycaemia proportional to degree of insulin resistance. *Diabetes Obesity and Metabolism*, *20*, 1526–1530.

de Rezende, L.F.M., Rey-López, J.P., Matsudo, R.V.K. and Luiz, O.d.C. (2014) Sedentary behaviour and health outcomes among older adults: a systematic review, *BMC Public Health,* 14:333.

Department of Health and Social Care (DHSC) (2019) UK Chief medical officers' physical activity guidelines. Available from https://www.gov.uk/government/publications/physical-activity-guidelines-uk-chief-medical-officers-report. Accessed 12/10/2019.

Dilnot, A. (2017) The burden of triumph: meeting health and social care needs. *Lancet*, 390 (10103):1630-1631.

Ding, D., Lawson, K., Kolbe-Alexander, T., Finkelstein, E., Katzmarzyk, P., Mechelen, W. and Pratt, M.. (2016). The economic burden of physical inactivity: A global analysis of major non-communicable diseases. The Lancet. 388(10051).

Dogra, S., Ashe, M.C., Biddle, S.J.H., Brown, W.J., Buman, M.P., Chastin, S., Gardiner, P.A., Inoue, S., Jefferis, B.J., Oka, K., Owen, N., Sardinha LB, Skelton DA, Sugiyama T, Copeland JL (2017) Sedentary time in older men and women: an international consensus statement and research priorities. *British Journal of Sports Medicine.* 51(21):1526-1532.

Duncan P.W., Weiner D.K., Chandler J. and Studenski S. (1990) Functional reach: a new clinical measure of balance. *Journal of Gerontology*, 45:M192–197.

Edwardson, C.L., Winkler, E.A.H., Bodicoat, D.H., Yates, T., Davies, M., Dunstan, D.W. and Healy, G. (2017) Considerations when using the activPAL monitor in field-based research with adult populations. *Journal of Health Science* 6: 162-178.

Eibling, D. (2018) Balance Disorders in Older Adults. *Clinics in Geriatric Medicine*, 34(2), pp175-181.

Ellingson, L.D., Kuffel, A.E., Vack, N.J. and Cook, D.B. (2014) Active and Sedentary Behaviours Influence Feelings of Energy and Fatigue in Women. *Medicine and Science in Sports and Exercise*, 46(1):192-200.

Ekelund, U., Brage, S., Besson, H., Sharp, S., Wareham, N.J. (2008) Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality?, *The American Journal of Clinical Nutrition*, 88(3): 612-617.

Ekelund U., Tarp J., Steene-Johannessen J., Hansen B.H., Jefferis B., Fagerland M.W., Whincup, P., Diaz, K.M., Hooker S.P., Chernofsky, A., Larson, M.G., Spartno, N., Ranachandran, S.V., Dohrn, I.M., Hagstromer, M., Edwardson, C. Yates, T., Shiroma, E. Anderssen, S.A. and Lee, I.M. (2019) Dose-response associations between accelerometry measured physical activity and sedentary time and all-cause mortality: systematic review and harmonised meta-analysis. *British Medical Journal [Internet].* Available from: http://www.bmj.com/lookup/doi/10.1136/bmj.l4570. Accessed 19/12/19.

Ensrud K.E., Blackwell T.L., Cauley J.A., Dam T-TL, Cawthon P.M., Schousboe J.T., Barrett-Connor E., Stone K.L., Bauer D.C. and Shikany J.M. (2014) Objective measures of activity level and mortality in older men. *Journal of the American Geriatric Society*, 62:2079–87.

European Innovation Partnership on Active and Healthy Ageing (2012) Conference Proceedings, Brussels. Available from: https://ec.europa.eu/eip/ageing/sites/eipaha/files/library/50acba37c1dff_A3-Action%20Plan%20Final%20v2.pdf. Accessed 02/12/2019.

Evenson K.R., Wen F. and Herring A.H. (2016) Associations of Accelerometry-Assessed and Self-Reported Physical Activity and Sedentary Behavior With All-Cause and Cardiovascular Mortality Among US Adults. American Journal of Epidemiology, 184:621-32.

Ezeugwu, V., Klaren, R.E., Hubbard, E.A., Mans, P.T. and Motl, R.W. (2015) Mobility disability and the pattern of accelerometer-derived sedentary and physical activity behaviors in people with multiple sclerosis, *Preventative Medicine* Reports, 2:241-246.

Falck, R.S., Davis, J.C. and Liu-Ambrose, T. (2017) What is the association between sedentary behaviour and cognitive function? A systematic review. *British Journal of Sports Medicine*;**51:**800-811.

Fanning, J., Porter, G., Awick, E.A., Ehlers, D.K., Roberts, S.A., Cooke, G., Burzynska, A.Z., Voss, MW., Kramer, A.F. and McAuley E. (2017) Replacing sedentary time with sleep, light, or moderate-to-vigorous physical activity: effects on self-regulation and executive functioning. *Journal of Behavioural Medicine*, 40(2):332-342.

Fanning J., Porter G., Awick E.A., Wójcicki T.R., Gothe N.P., Roberts S.A., Ehlers D.K., Motl R.W., McAuley E. (2016) Effects of a DVD-delivered exercise program on patterns of sedentary behavior in older adults: a randomized controlled trial. *Preventative Medicine Reports*, 8(3):238-43.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Fitzgerald, J.D., Johnson, L., Hire, D.G., Ambrosius, W.T., Anton, S.D., Dodson, J.A., and Group, L.S.R. (2015). Association of objectively measured physical activity with cardiovascular risk in mobility limited older adults. *Journal of the American Heart Association*, 4(2), e001288.

Fitzsimons, C.F., Kirk, A., Baker, G., Michie, F., Kane, C. and Mutrie, N. (2013) Using an individualised consultation and activPal ™ feedback to reduce sedentary time in older Scottish adults: Results of a feasibility and pilot study. *Preventative Medicine* 57:718-720.

Freedson, P.S., Melanson, E. and Sirard, J. (1998) Calibration of the Computer Science and Applications, Inc. accelerometer. *Medicine and Science in Sports and Exercise*, 30:777-81.

Frith, J. and Davison, J. (2013) Falls. *Reviews in Clinical Gerontology*, 23; 101-117.

Gardiner, B., Thuné-Boyle, I., Iliffe, S., Fox, F., Jefferis, B.J., Hamer, M., Tyler, N. and Wardle, J. (2014) 'On Your Feet to Earn Your Seat', a habit-based intervention to reduce sedentary behaviour in older adults: study protocol for a randomised controlled trial, *Trials* 15:368.

Gardiner, B., Smith, L., Aggio, D., Iliffe, S., Fox, K., Jefferis, B. and Hamer, M. (2015) 'On Your Feet to Earn Your Seat': update to randomised controlled trial protocol, *Trials* 16:330.

Gardner, B., Smith, L., Lorencatto, F., Hamer, M., & Biddle, S. J. (2016). How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. *Health psychology review*, *10*(1), 89–112.

Gardiner, P.A., Clark, B.K., Healy, G.N., Eakin, E.G., Winkler, E.A., Owen, N. (2011) Measuring older adults' sedentary time: reliability, validity and responsiveness. *Medicine and Science in Sports and Exercise,* 43:2127-2133.

Gardiner, P., Eakin, E., Healy, G. and Owen, N. (2011) Feasibility of Reducing Older Adults' Sedentary Time. *American Journal of Preventative Medicine*, 41(2):174-177.

Gennuso, K., Gangnon, R.E., Matthews, C.E., Thraen-Borowski, K.M., and Colbert, L.H. (2013) Sedentary Behaviour, Physical Activity, and Markers of Health in Older Adults. *Medicine Science in Sports and Exercise*, 45(8): 1493-1500.

Gennuso, K. P., Matthews, C. E., & Colbert, L. H. (2015). Reliability and Validity of 2 Self-Report Measures to Assess Sedentary Behavior in Older Adults. *Journal of physical activity & health*, *12*(5), 727–732.

Gennuso, K.P., Thraen-Borowski, K.M., Gangnon, R.E., Colbert, L.H. (2016) Patterns of sedentary behavior and physical function in older adults. *Aging Clinical Experimental Research* 28:943–950.

Gibbs, B.B., Reis, J.P., Schelbert, E.B., Craft, L.L., Sidney, S., Lima, J. and Lewis, C.E. (2014). Sedentary screen time and left ventricular structure and function: The CARDIA study. *Medicine and Science in Sports and Exercise*, 46:276-283.

Giné-Garriga, M., Coll-Planas, L. , Guerra, M., Domingo, À., Roqué, M., Caserotti, P., Denkinger, M., Rothenbacher, D., Tully, M.A., Kee, F., McIntosh, E., Martín-Borràs, C., Oviedo, G.R., Jerez-Roig, J., Santiago, M., Sansano, O., Varela, G., Skjødt, M., Wirth, K., Dallmeier, D., Klenk, J., Wilson, J.J., Blackburn, N.E., Deidda, M., Lefebvre, G., González, D. and Salvà, A. (2017) The SITLESS project: exercise referral schemes enhanced by self-management strategies to battle sedentary behaviour in older adults: study protocol for a randomised controlled trial*, Trials*, 18:221.

Gomersall S.R., Maher C., English C.K., Rowland A. and Olds T. (2015) Time regained: when people stop a physical activity program, how does their time use change? A randomised controlled trial. *PLoS ONE*; 10(5).

Goodpaster B.H., Park, S.W., Harris, T.B., Kritchevsky, S.B., Nevitt, M., Schwartz, A.V., Simonsick, E.M., Tylavsky, F.A., Visser, M. and Newman, A.B. (2006) The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *Journal of Gerontology: Series A*, 61(10):1059–1064.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., Wallace, R.B. (1994) A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *Journals of Gerontology*, 49(2), 85-94.

Hagberg J.M., Allen, W.K., Seals, D.R., Hurley, B.F., Ehsani, A.A. and Holloszy, J.O. (1985) A hemodynamic comparison of young and older endurance athletes during exercise. *Journal of Applied Physiology* **58**: 2041-2046.

Hagger, M.S., Weed, M. (2019) DEBATE: Do interventions based on behavioral theory work in the real world? *International Journal of Behavioral Nutrition and Physical Activity* **16,** 36.

Hagströmer M, Rizzo, N.S. and Sjöström M. (2014) Associations of season and region on objectively assessed physical activity and sedentary behaviour. *Journal of Sports Science*; 32: 629–634.

Hallgren, M., Nguyen, T., Owen, N., Stubbs, B., Vancampfort, D., Lundin, A., Dunstan, D., Bellocco, R. and Lagerros, Y. (2019). Cross-sectional and prospective relationships of passive and mentally active sedentary behaviours and physical activity with depression. *The British Journal of Psychiatry*, 1-7.

Hallgren, M., Nguyen, TTD., Owen, N. Vancampfort, D., Smith, L., Dunstan, DW., Andersson, G., Wallin, P. and Ekblom-Bak, E. (2020) Associations of interruptions to leisure-time sedentary behaviour with symptoms of depression and anxiety. *Translational Psychiatry* **10,** 128.

Hallgren, Mats & Dunstan, D. & Owen, Neville. (2020). Passive Versus Mentally Active Sedentary Behaviors and Depression. *Exercise and sport sciences reviews*. 48. 10.1249.

Hamer, M., Lavoie, K.L. and Bacon, S.L. (2014) Taking up physical activity later in life and healthy ageing: the English longitudinal study of ageing. *British Journal of Sports Medicine*, 48:239-243.

Hardman, A.E. and Stensel, D.J. (2009) *Physical Activity and Health, the evidence explained (2nd ed.).* Routledge; London

Hart, T.L., Ainsworth, B.E. and Locke, C. (2011) Objective and Subjective Measures of Sedentary Behaviour and Physical Activity, *Medicine and Science in Sports and Exercise*, 43(3):449-456.

Harvey, J.A., Chastin, S.F. and Skelton, D. (2013) Prevalence of Sedentary Behavior in Older Adults: A Systematic Review, *International Journal of Environmental Research and Public Health,* 10, 6645-6661.

Harvey, J.A., Chastin, S.F.M., and Skelton, D. (2015) How Sedentary are Older People? A Systematic Review of the Amount of Sedentary Behaviour. *Journal of Aging and Physical Activity*, 23:471-487.

Healy, G.N., Dunstan, D.W., Salmon, J., Cerin, E., Shaw, J.E., Zimmet, P. and Owen, N. (2008) *Diabetes Care*, 31 (4) 661-666.

Healy, G.N., Clark, B.K., Winkler, E.A.H., Gardiner, P.A., Brown, W.J., Matthews, C.E. (2011) Measurement of adults' sedentary time in population-based studies. *American Journal of Preventative Medicine.* 41:216-227.

Healthy Ireland (2018) Get Ireland Healthy. The National Physical Activity Plan for Ireland. Department of Health, Dublin. Avaliable from: https://www.getirelandactive.ie/Professionals/National-PA-Plan.pdf. Accessed 03/12/19.

Hemming, K., Girling, A.J., Sitch, A.J. *et al.* Sample size calculations for cluster randomised controlled trials with a fixed number of clusters. *BMC Medical Research Methodology* **11,** 102.

Herman, T., Iladi, N. and Hausdorff, J.M. (2011) Properties of the 'Timed Up and Go' Test: More than Meets the Eye. *Gerontology*, 57:203-210.

Heesh, K.C., Hill, R., Aguilar-Farias, N., van Uffelen, J.G.Z. and Pavey, T. (2018) Validity of objective methods for measuring sedentary behaviour in older adults: a systematic review. *International Journal of Behavioural Nutrition and Physical Activity* 15:119.

Herbolsheimer, F., Riepe, M. W., & Peter, R. (2018). Cognitive function and the agreement between self-reported and accelerometer-accessed physical activity. *BMC geriatrics*, *18*(1), 56.

Higgins, J., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. and Welch, V. (eds) (2019) Cochrane Handbook for Systematic Reviews of Interventions, Version 6, 2019. Available from: https://training.cochrane.org/handbook/current. Accessed 24/08/2020.

Hildebrand M., van Hees V.T., Hansen, B.H. and Ekelund, U. (2014) Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Medicine and Science in Sports and Exercise*, 46:1816-24.

Howe, T.E., Rochester, L., Neil, F., Skelton, D.A. and Ballinger, C. (2011) Exercise for improving balance in older people. *Cochrane Database System Review* 9(11): CD004963.

Institute for Fiscal Studies (IFS) (2017) Public spending on adult social care in England- IFS Briefing Note BN200. Available from: https://www.ifs.org.uk/uploads/publications/bns/BN200.pdf. Accessed 16/01/20.

Institute for Social and Economic Research (ISER) (2017) Understanding Society. The UK Household Longitudinal Study, Wave 7. Available from: https://www.understandingsociety.ac.uk/. Accessed 10/12/2019.

Inouye, S. K., Studenski, S., Tinetti, M. E., & Kuchel, G. A. (2007). Geriatric syndromes: clinical, research, and policy implications of a core geriatric concept. *Journal of the American Geriatrics Society*, *55*(5), 780–791.

Jakobsen, J.C., Gluud, C., Wetterslev, J. and Winkel, P. (2017) When and how should multiple imputation be used for handling missing data in randomised clinical trials – a practical guide with flowcharts. *BMC Medical Research Methodology* **17,** 162 (2017).

Janssen, X. and Cliff, D. (2015) Issues Related to Measuring and Interpreting Objectively Measured Sedentary Behavior Data, *Measurement in Physical Activity and Exercise Science*, 19:3, 116-1.

Jefferis B.J., Parsons T.J., Sartini C., Ash, S., Lennon, L.T., Papacosta, O., Morris, R.W., Wannamethee, S.G., Lee, I.M. and Whincup, P.H. (2018) Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of accumulation? *British Journal of Sports Medicine*, 53:1013-1020.

Jones, C.J., and Rickli, RE. (2002) Measuring Functional Fitness of Older Adults. *The Journal on Active Aging*, March- April 2002.

Jylhävä, J., Pedersen, N.L. and Hägg, S. (2017) Biological Age Predictors (Review) *EBiomedicine*, 21: 29-36.

Kallings, L.V., Johnston, J.S., Fisher, R.M., de Faire, U., Stahle, A., Hemmingsson, E. and Hellénius,M-L. (2009) Beneficial effects of individualised physical activity on body composition and cardiometabolic risk factors: results from a randomized controlled trial. *European Journal of Cardiovascular Preventative Rehabilitation*, 16:80-84.

Kang, M. and Rowe, D. (2015) Issues and Challenges in Sedentary Behavior Measurement *Measurement in Physical Education and Exercise Science*, 19:3, 105-115.

Katzmarzyk, P.T., Church, T.S., Craig, C.L. and Bouchard, C. (2009) Sitting time and mortality from all causes, cardiovascular disease and cancer. *Medicine and Science in Sports and Exercise*, 41:998-1005.

Kesse-Guyo, E., Charreire, H., Andreeva, V.A., Touvier, M., Hercberg, S. and Galan P., (2012) Cross 653 sectional and longitudinal associations of different sedentary behaviors with cognitive 654 performance in older adults. *PLoS ONE*, 7(10):e47831.

Kings Fund (2018). What is happening to life expectancy in the UK? Available from: https://www.kingsfund.org.uk/publications/whats-happening-life-expectancy-uk. Accessed 29/11/19.

Koltyn, K.F, Crombie, K.M., Brellenthin, A.G., Leitzelar, B., Ellingson, L.D., Renken, J. and Mahoney, J.E. (2019) Intervening to reduce sedentary behaviour in older adults – pilot results, *Health Promotion Perspectives*, 9(1), 71-76.

Konrad, H.R., Girardi, M. and Helfert, R. (1999), Balance and Aging. *The Laryngoscope*, 109: 1454-1460.

Kontis V., Bennett J.E., Mathers C.D., Li G., Foreman K. and Ezzati M. (2017) Future life expectancy in 35 industrialised countries: projections with a Bayesian model ensemble. *Lancet*; 389: 1323–35.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J. and Freedson, P. (2011) Validation of Wearable Monitors for Assessing Sedentary Behaviour. *Medicine and Science in Sports and Exercise,* 43(8): 1561-1567.

Kozy-Keadle, S.K., Arem, H., Moore, S.C., Sampson, J.N., and Matthews, C. (2015) Impact of changes in television viewing time and physical activity on longevity: a prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity* **12,** 156.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J. and Freedson, P. (2011) Validation of Wearable Monitors for Assessing Sedentary Behaviour. *Medicine and Science in Sports and Exercise*, 43(8): 1561-1567.

Kozy-Keadle, S., Lyden, K., Hickey, A., Ray, E.L., Fowke, J.H., Freedson, P. and Matthews, C.E. (2014) Validation of a previous day recall for measuring the location and purpose of active and sedentary behaviors compared to direct observation. *International Journal of Behavioral Nutrition and Physical Activity,* 2014,11:12.

Lagiewka K. (2012) European innovation partnership on active and healthy ageing: triggers of setting the headline target of 2 additional healthy life years at birth at EU average by 2020. *Archives of Public Health*; 70:23.

Lally, P., Wardle, J. and Gardiner, B. (2011) Experiences of habit formation: a qualitative study. *Psychology and Health Medicine*; 16(4):484-489.

Landi, F., Abbatecola, A.M., Provinciali, M., Carsonello, A., Bustacchini, S., Manigrasso, L., Cherubini, A., Bernabei, R. and Lattanzio, F. (2010) Moving Against Frailty: does physical activity matter? *Biogerentology* 11:537-545.

Landi F, Calvani R,Tosato M, Bernabei, R., Onder, G. and Marzetti, E. (2016) Impact of physical function impairment and multimorbidity on mortality among community-living older persons with sarcopaenia: results from the ilSIRENTE prospective cohort study. *British Medical Journal Open,* 6:e008281.

Leask, C. F., Harvey, J. A., Skelton, D. A., & Chastin, S. F. (2015). Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). *European review of aging and physical activity : official journal of the European Group for Research into Elderly and Physical Activity*, *12*, 4.

Lee I.M., Shiroma E.J., Lobelo F., Puska P., Blair S.N., Katzmarzyk P.T. (2012) Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*, 380:219-29.

Lee I.M., Shiroma E.J., Evenson K.R., Kamada M., LaCroix A.Z. and Buring J.E. (2018) Accelerometer-Measured Physical Activity and Sedentary Behavior in Relation to All-Cause Mortality: The Women's Health Study. *Circulation*, 137:203-5.

Leung, P.M., Ejupi, A., van Schooten, K.S., Aziz, O., Feldman, F., Mackey, D.C., Ashe, M.C. and Robinovitch, S.N. (2017) Association between Sedentary Behaviour and Physical, Cognitive, and Psychosocial Status among Older Adults in Assisted Living. Biomedical Research International, 2017:9160504.

Lewis, L.K., Rowlands, A.V., Gardiner, P.A., Standage, M., English, C., Olds, T. (2016) Small Steps: Preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults. *Maturitas* 85: 64-70.

Lima, C.A., Ricci, N.A., Nogueira, E.C. and Perracini, M.R. (2018) The Berg Balance Scale as a clinical screening tool to predict falls risk in older adults: a systematic review. *Physiotherapy*, 104(4):383-394.

Lindsay-Smith, G., Banting, L., Eime, R., O'Sullivan, G., van Uffelen, J.G.Z. (2017) The association between social support and physical activity in older adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, 27; 14(1):56.

Liu, J.D., Quach, B. and Chung, P.K. (2019) Further understanding of the Senior Fitness Test: Evidence from community-dwelling high function older adults in Hong Kong. *Archives of Gerontology & Geriatrics.* 2019; 82:286-292.

Loprinzi, P.D., Lee, H., & Cardinal, B.J. (2014). Daily movement patterns and biological markers among adults in the United States. *Preventive Medicine*, 60, 128–130.

Lyden, K., Petruski, N., Mix, S., Staudenmayer, J. and Freedson, P. (2014) Direct Observation is a Valid Criterion for Estimating Physical Activity and Sedentary Behavior. *Journal of Physical Activity and Health,* 11(4):860-863.

MacMillan, F., Fitzsimons, C., Black, K., Granat, M.H., Grant, M., Grealy, M., Macdonald, H., McConnachie, A., Rowe, D., Shaw, R. and Skelton, D., Mutrie, N. (2011) West End Walkers 65+: A randomised controlled trial of primary care=based walking intervention for older adults: Study rationale and design. *BMC Public Health*, 11:120.

Magistro, D., Liubicich, M.E., Candela, F and Ciairano, S. (2014) Effect of Ecological Walking Training in Sedentary Elderly People: Act on Ageing Study. *The Gerontologist* (54)4:611-623.

McGowan, L. J., Powell, R., and French, D. P. (2019). How Acceptable is Reducing Sedentary Behavior to Older Adults? Perceptions and Experiences Across Diverse Socioeconomic Areas, *Journal of Aging and Physical Activity*, *27*(5), 642-652.

Maher, J.P., Sliwinski, M.J., and Conroy, D.E. (2017). Feasibility and preliminary efficacy of an intervention to reduce older adults' sedentary behavior. *Translational Behavioral Medicine*, 7(1), 52–61.

Mancini, M., & Horak, F. B. (2010). The relevance of clinical balance assessment tools to differentiate balance deficits. *European journal of physical and rehabilitation medicine*, *46*(2), 239–248.

Manini T.M., Everhart J.E., Patel K.V., Schoeller, D.A., Colbert, L.H., Visser, M., Tylavsky, F., Bauer, D.C., Goodpaster, B.H. and Harris, T.B (2006) Daily activity energy expenditure and mortality among older adults. *Journal of the American Medical Association*, 296:171-9.

Mason, R. C., Horvat, M., & Nocera, J. (2016). The Effects of Exercise on the Physical Fitness of High and Moderate-Low Functioning Older Adult Women. *Journal of Aging Research*, 8309284.

Matei, R., Thuné-Boyle, I., Hamer, M., Iliffe, S., Fox, K., Jefferis, B.J. and Gardiner, B. (2015) Acceptability of a theory-based sedentary behaviour reduction intervention for older adults ('On Your Feet to Earn Your Seat') *BMC Public Health*, 15:606.

Matson T.E., Renz A.D., Takemoto M.L., McClure J.B., Rosenberg D.E. (2018) Acceptability of a sitting reduction intervention for older adults with obesity. *BMC Public Health*,7;18(1):706.

Matthews, C.E., Chen, K.Y., Freedson, P.S., Buchowski, M.S., Beech, B.M., Pate, R.R. and Troriano, R.P. (2008) Amount of time spent in sedentary behaviours in the United States. American Journal of Epidemiology, 167(7):875-881.

Matthews, C.E., Hagströmer, M., Pober, D.M., and Bowles, H.R. (2012). Best practices for using physical activity monitors in population-based research. *Medicine and science in sports and exercise*, *44*(1 Suppl. 1), 68–76.

Matthews, C.E., Keadle, S.K., Troiano, R.P., Kahle, R., Koster, A., Brychta, R., Van Domelen, D., Caserotti, P., Chen,K.Y., Harris, T.B and Berrigan, D. (2016) Accelerometer-measured dose-response for physical activity, sedentary time, and mortality in US adults, *The American Journal of Clinical Nutrition*, Volume 104:5, 1424-1432.

McAuley E., Wójcicki T.R., Gothe N.P., Mailey E.L., Szabo, A.N., Fanning J., Olson E.A., Phillips, S.M., Motl, R.W. and Mullen S.P. (2013) Effects of a DVD-delivered exercise intervention on physical function in older adults. *J Gerontology: Series A* 68(9):1076-82.

McAuley E., Wójcicki T.R., Gothe N.P., Mailey E.L., Szabo A.N., Fanning J., Olson E.A., Phillips S.M., Motl R.W. and Mullen S.P. (2013) Effects of a DVD-delivered exercise intervention on physical function in older adults. *J Gerontology: Series A*, 68(9):1076-82.

McCambridge J., Witton J., Elbourne D.R. (2014) Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *Journal of Clinical Epidemiology*, 67(3):267-77.

McGill, P. (2010) Illustrating Ageing in Ireland North and South: Key Facts and Figures. Belfast: Centre for Ageing Research and Development in Ireland. Available at: https://www.cardi.ie/userfiles/Master%20CARDI%20Statistical%20Paper_%28web%29.pdf. Accessed 10/07/17.

McGowan, L.J., Devereux-Fitzgerald, A., Powell, R. and French, D.P. (2018) How acceptable do older adults find the concept of being physically active? A systematic review and meta-synthesis, *International Review of Sport and Exercise Psychology*, 11:1, 1-24.

McGowan, L. J., Powell, R., & French, D. P. (2019). How Acceptable is Reducing Sedentary Behavior to Older Adults? Perceptions and Experiences Across Diverse Socioeconomic Areas, *Journal of Aging and Physical Activity*, *27*(5), 642-652. Retrieved Jan 14, 2020, from https://journals.humankinetics.com/view/journals/japa/27/5/article-p642.xml.

Michie, S., Johnston, M., Abraham, C., Lawton, R., Parker, D. and Walker, A.E. (2005) Making Psychological Theory Useful for Implementing Evidence Based Practice: A Consensus Approach. *Quality & safety in health care*. 14. 26-33.

Michie, S., van Stralen, M.M. & West, R. (2011) The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science* **6,** 42.

Michie, S. & Johnston, M. (2012) Theories and techniques of behaviour change: Developing a cumulative science of behaviour change, Health Psychology Review, 6:1, 1-6.

Michie S., Richardson M., Johnston M., Abraham C., Francis, J., Hardeman W., Eccles, M.P., Cane, J. & Wood C.E. (2013) The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. *Annals of Behavioral Medicine*, 46(1):81-95.

Michie, S., West, R., Sheals, K., Godinho, C.A. (2018) Evaluating the effectiveness of behavior change techniques in health-related behavior: a scoping review of methods used, *Translational Behavioral Medicine*, 8(2), 212–224.

Mitchell, R.J., Lord, S.R., Harvey, L.A., & Close, J.C. (2015). Obesity and falls in older people: Mediating effects of disease, sedentary behaviour, mood, pain and medication use. *Archives of Gerontology and Geriatrics*, 60(1), 52–58.

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery*, 8(5):336 – 341.

Moloney, M.C., Godfrey, A., O'Connor, V. and O'Leighin (2007) Mobility in Patients with Venous Leg Ulceration. *European Journal of Vascular and Endovascular Surgery* 33(4); 488-93.

Morris, J.N., Heady, J.A., Raffle, P.A., Roberts, C.G. and Parks, J.W. (1953) Coronary heart-disease and physical activity of work. *Lancet*, 21;262(6795):1053-1057.

Morris J.N. and Crawford M.D. (1958) Coronary heart disease and physical activity of work: evidence of a national necropsy survey, *British Medical Journal*, 2:1485–96.

Morris J.N., Pollard R., Everitt M.G. and Chave S.P.W. (1980) Vigorous exercise in leisure-time: protection against coronary heart disease. *Lancet*, 2: 1207–10.

Morris J.N., Clayton D.G., Everitt M.G., Semmence A.M. and Burgess E.H. (1990) Exercise in leisure time: coronary attack and death rates. *British Heart Journal*, 63:325–34.

Munir, F., Biddle, S.J.H., Davies, M.J., Dunstan, D, Esliger, D., Gray, L.J., Jackson, B.R., O'Connell, S.E., Yates, T. and Edwardson, C.L. (2018) *Stand More AT Work (SMArT Work)*: using the behaviour change wheel to develop an intervention to reduce sitting time in the workplace. *BMC Public Health* **18,** 319.

Mutrie, N., Doolin, O., Fitzsimons, C., Grant, P.M., Granat, M., Grealy, M., Macdonald, H., MacMillan, F., McConnachie, A., Rowe, D., Shaw, R. and Skelton, D. (2012) Increasing older adults' walking through primary care: results of a pilot randomised controlled trial. *Family Practice* 29:633-643.

Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S. and Atwood, J.E. (2002) 'Exercise Capacity and mortality among men referred for exercise testing'. *New England Journal of Medicine* 346:793-801.

Naber, A., Molitor, W.L., Farriell, A., Honius, K. and Poppe, B (2019) The Exploration of Occupational Therapy Interventions to Address Sedentary Behaviour and Pain Among Older Adults. *Journal of Ageing and Physical Activity,* 12:1-8.

National Health Service (NHS) UK (2019) Physical Activity Guidelines for Older Adults. Available from: (https://www.nhs.uk/live-well/exercise/physical-activity-guidelines-older-adults/. Accessed 06/12/2019.

National Institute for Health and Care Excellence (NICE) (2013) Falls in older people: assessing risk and prevention. Clinical guideline [CG161] Available from: https://www.nice.org.uk/guidance/cg161. Accessed 10/12/2019.
National Institute for Health and Care Excellence (NICE) (2014) Behaviour Change: Individual Approaches (Public Health Guideline PH49). Available from: https://www.nice.org.uk/guidance/ph49/chapter/1-recommendations#recommendation-8-ensure-interventions-meet-individual-needs. Accessed 15/01/2020.

National Institute for Health and Care Excellence (2018) NICE impact falls and fragility fractures. NICE, London. Available from: https://www.bgs.org.uk/sites/default/files/content/resources/files/2018-08-29/NICE-Impact-falls-and-fragility-fractures.pdf Accessed 19/08/2019.

nNodim J.O. and Yung R.L. (2015) Balance and its Clinical Assessment in Older Adults - A Review. *Journal of Geriatric Medicine and Gerontology*,1(1):003.

Nooho, M.M., Aparajit, B.D. and Hussain, M.E. (2014) Relevance of balance measurement tools and balance training for fall prevention in older adults. *Journal of Clinical Gerontology and Geriatrics* 5: 31-35.

Northey, J.M., Cherbuin, N., Pumpa, K.L., Smee, D.J. and Rattray, B. (2018) Exercise interventions for cognitive function in adults older than 50: a systematic review with meta-analysis, *British Journal of Sports Medicine*, 52, 154-160.

Northern Ireland Statistics and Research Agency (NISRA) (2019) 2018-based Population Projections for Northern Ireland, Northern Ireland Statistics and Research Agency. Available from: https://www.nisra.gov.uk/sites/nisra.gov.uk/files/publications/NPP18_PN.pdf, Accessed 29/11/19.

Nunes, P., Flores, T.R., Mielke, G.I., Thumé, E., Facchini, L. and Augusto, P. (2016) Multimorbidity and mortality in older adults: A systematic review and meta-analysis *Archives of gerontology and geriatrics*, 67: 130-8.

O'Donovan, G., Blazevich, A.J., Boreham, C., Cooper, A.R., Crank, H Ekelund, U., Fox, K.R., Gately, P., Giles-Corti, B., Gill, J.M.R., Hamer, M., McDermott, I., Murphy, M., Mutrie, N., Reilly, J.J., Saxton, J.M & Emmanuel Stamatakis (2010) The ABC of Physical Activity for Health: A consensus statement from the British Association of Sport and Exercise Sciences, *Journal of Sports Sciences*, 28:6, 573-591.

Office of The First Minister and Deputy First Minister Northern Ireland (2015) A profile of older people in Northern Ireland – Annual Update (2015). Northen Ireland Statistics and Research Agency, Stormont, Belfast. Available from: https://www.executiveoffice-ni.gov.uk/sites/default/files/publications/ofmdfm/a-profile-of-older-people-in-ni-annual-update-2015.pdf. Accessed 15/08/2019.

Office for National Statistics (ONS) (2017). National population projections: 2018-based - Office for National Statistics. Available from: https://www.ons.gov.uk/releases/nationalpopulationprojections2016basedstatisticalbulletin. Accessed 29/11/19.

Office for National Statistics (ONS) (2018) Health state life expectancies, UK: 2015 to 2017. Available from: www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandlifeexpectancies/bulletins/healthstatelifeexpectanciesuk/2015to2017. Accessed 30/11/19.

Ogden J. Celebrating variability and a call to limit systematisation: the example of the Behaviour Change Technique Taxonomy and the Behaviour Change Wheel. *Health Psychology Reviews*, 2016;10(3):245-250.

Owen, N., Sugiyama, T., Eakin, E.E., Gardiner, P., Tremblay, M.S. and Sallis, J. (2011) Adults' Sedentary Behaviour Determinants and Interventions. *American Journal of Preventative Medicine*, Vol.41(2): 189-196.

Paffenbarger R.S. Jr, Hyde R.T., Wing A.L. and Hsieh C.C. (1986) Physical activity, all-cause mortality, and longevity of college alumni. *New England Journal of Medicine*, 314:605–13.

Parkin, D.M., Boyd, L. and Walker, L.C. (2011). The fraction of cancer attributable to lifestyle and environmental factors in the UK in 2010. *British Journal of Cancer*, 105: S77–S81.

Patterson, R., McNamara, E., Tainio, M., (2018) Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *European Journal of Epidemiology*, 33:811-29.

Peacock, J.L. and Peacock, P.J. (2011) *Oxford Handbook of Medical Statistics*. Oxford University Press.

Peduzzi, P., Concato, J., Kemper, E., Holford, T.R. and Feinstein, A.R. (1996) A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology* 49:1373-1379.

Petry, N.M., Andrade, L.F., Barry, D. and Byrne, S. (2013) A Randomised Study of Reinforcing Ambulatory Exercise in Older Adults. *Psychology and Ageing* (28)4:1164-1173.

Podsiadlo, D. & Richardson, S. (1991) The Timed "Up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons. *Journal of the American Geriatric Society*; 39:142-148.

Power, M., Bullinger, M., & Harper, A. (1999). The World Health Organization WHOQOL-100: Tests of the universality of quality of life in 15 different cultural groups worldwide. *Health Psychology*, 18(5), 495–505.

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Available from: http://www.prisma-statement.org/ Accessed 15 January 2017.

Prince S.A., Adamo K.B., Hamel M.E., Hardt J., Gorber C.S., Tremblay M. (2008) A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*; 5:56.

Prince, S. A., Saunders, T. J., Gresty, K., & Reid, R. D. (2014). A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. *Obesity reviews: an official journal of the International Association for the Study of Obesity*, *15*(11), 905–919.

Prochaska, J. and DiClemente, C. (1983) Stages and processes of self-change in smoking: toward an integrative model of change. Journal of Consulting and Clinical Psychology, 5, 390–395.

Proctor, D.N., Shen, P.H., Dietz, N.M., Eikhoff, T.J., Lawler, L.A., Ebersold, E.J., Loeffler, D.I. and Joyner, M.J. (1998) Reduced leg blood flow during dynamic exercise in older endurance trained men. *Journal of Applied Physiology*, 85, 68-75.

Public Health England (2018) Population change and trends in life expectancy. Public Health England. Available from: https://www.gov.uk/government/publications/health-profile-for-england-2018/chapter-1-population-change-and-trends-in-life-expectancy. Accessed 29/11/2019.

Public Health England (2019) Guidance Physical activity: applying ALL Our Health. Public Health England, Available from: https://www.gov.uk/government/publications/physical-activity-applying-all-our-health/physical-activity-applying-all-our-health. Accessed 02/12/19.

Rikli R.E. and Jones C.J. (1999) The development and validation of a functional fitness test for community-residing older adults. *Journal of Aging and Physical Activity*, 7: 129–161.

Jones, C.J. and Rickli, R.E. (2002) Measuring functional fitness of older adults. The Journal on Active Aging, Mar/Apr 2002.

Rivière, F., Aubert, S., Omorou, A. Y., Ainsworth, B. E., & Vuillemin, A. (2018). Taxonomy-based content analysis of sedentary behavior questionnaires: A systematic review. *PloS one*, *13*(3), e0193812.

Roberts, L.M., Jaeger, B.C., Baptista, L.C., Harper, S.A., Gardner, A.K., Jackson, E.A., Pekmezi, D., Sandesara, B., Manini, T.M., Anton, S.D. and Buford, T.W. (2019) Wearable Technology To Reduce Sedentary Behavior And CVD Risk In Older Adults: A Pilot Randomized Clinical Trial. *Clinical Interventions in Aging*. Oct 23; 14:1817-1828.

Robinson, S. (1938) Experimental studies of physical fitness in relation to age. *Arbeitsphysiologie*, 10, 251-323.

Rhodes, R.E. and Blanchard, C.M. (2006) Do sedentary motives adversely affect physical activity? Adding cross-behavioural cognitions to the theory of planned behaviour. *Psychology and Health*, 23(7)789-805.

Rollo, S., Gaston, A. and Prapavessis, H. (2016) Cognitive and Motivational Factors Associated with Sedentary Behavior: A Systematic Review. *AIMS Public Health*. Nov 28;3(4):956-984.

Rose, D.J., Lucchese, N., Wiersma, L.D. (2006) Development of a multidimensional balance scale for use with functionally independent older adults. *Archives of Physical Medicine and Rehabilitation*, 87: 1478–1485.

Rosenberg, D.E., Gell, N.M., Jones, S.M., Renz, A., Kerr, J., Gardiner, P.A., Arterburn, D. (2015) The Feasibility of Reducing Sitting Time in Overweight and Obese Older Adults. *Health Education and Behaviour*, 42(5):669-76.

Rosenberg, D.E., Bellettiere, J., Gardiner, P.A., Villarreal, V.N., Crist, K., & Kerr, J. (2016). Independent associations between sedentary behaviors and mental, cognitive, physical, and functional health among older adults in retirement communities. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences,* 71(1), 78–83.

Rosenberg, D.E., Norman, G.J., Wagner, N., Patrick, N., Calfas, K.J., and Sallis, J.F. (2010) Reliability and Validity of the Sedentary Behaviour Questionnaire (SBQ) for Adults, *Journal of Physical Activity and Health*, 7(6) 697-705**.**

Rossat, A., Fantino, B., Nitenberg, C., Annweiler, C., Poujol, L., Herrmann, F.R. and Beauchet, O. (2010) Risk factors for falling in community-dwelling older adults: Which of them are associated with the recurrence of falls? *The Journal of Nutrition, Health and Ageing*, Vol. 14(9):787-791.

Rowe, D.A., and Kang, M. (2015) "Don't Just Sit There – Do Something!" – The Measurement of Sedentary Behavior, *Measurement in Physical Education and Exercise Science*, 19:3, 103-104.

Rowlands, A.V. and Stiles, V.H. (2012) Accelerometer counts and raw acceleration output in telation to mechanical loading. *The Journal of Biomechanics*, 45, 448-454.

Ryan, J., Lopian, L., Le, B., Edney, S., Van Kessel, G., Plotnikoff, R., Vandelanotte, C., Olds, T. and Maher, C. (2019) It's not raining men: a mixed-methods study investigating methods of improving male recruitment to health behaviour research. *BMC Public Health* **19,** 814.

Sallis, J.F., Owen, N., Fisher, E.B. (2008) Ecological models of health behaviour. In Glanz, K., Rimmer, B.K., Vinswanath, K. (eds). *Health Behaviour and Health Education.* 4th ed. San Francisco, CA: Josely-Bass: 465-485.

Sanderson, W.C. & Scherbov, S. (2005) Average Remaining Lifetimes Can Increase As Human Populations Age. *Nature* 435(7043):811-813.

Santarossa, S., Kane, D., Senn, C.Y., Woodruff, S.J. (2018) Exploring the Role of In-Person Components for Online Health Behavior Change Interventions: Can a Digital Person-to-Person Component Suffice? *Journal of Medical Internet Research*. Apr 11;20(4):e144.

Santos, D.A., Silva, A.M., Baptista, F., Santos, R., Vale, S., Mota, J., Sardinha, L.B., (2012) Sedentary Behaviour and Physical Activity Are independently related to functional fitness in older adults. *Experimental Gerontology*, 47; 908-912.

Scallan E., Staines A., Fitzpatrick P., Laffoy, M. and Kelly, A. (2004) Unintentional injury in Ireland: a comparison of mortality and morbidity data. *Journal of Public Health*, 26(1):6-7.

Sardinha, L.B., Santos, D.A., Silva, A.M., Baptista, F., Owen, N. (2015) Breaking-up sedentary time is associated with physical function in older adults. J*. Gerontol A Biol Sci Med Sci*. Jan;70(1):119-24.

Sarkisian, C.A., Prohaska, T.R., Davis, C. and Weiner, B. (2007) Pilot test of an attribution retraining intervention to raise walking levels in sedentary older adults. *Journal of the American Geriatric Society,* 55(11):1842-1846.

Sedentary Behaviour Research Network (SBRN). Letter to the editor: standardised use of the terms "sedentary" and "sedentary behaviours". *Applied Physiology, Nutrition and Metabolism*, 2012; 37(3):540-542.

Schalock, R. L., Verdugo, M. A., Gomez, L. E., & Reinders, H. S. (2016). Moving us toward a theory of individual quality of life. *American Journal on Intellectual and Developmental Disabilities*, 121(1), 1–12.

Sjogren, P., Fisher, R., Kallings, L., Svenson, U., Roos, G. and Hellénius, M-L. (2014) Stand up for your health – avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people. *British Journal of Sports Medicine*, 48:1407-1409.

Stalenhoef P.A., Diederiks J.P., Knottnerus J.A., Kester A.D. and Crebolder HF. (2002) A risk model for the prediction of recurrent falls in community dwelling elderly: a prospective cohort study*. Journal of Clinical Epidemilogy*, 55(11):1088-1094.

Stamatakis, E., Ekelund, U., Ding, D., Hamer, M., Bauman, A. and Lee I.M. (2019) Is it time for quantitative public health guidelines on sitting? A narrative review of sedentary behaviour research paradigms and findings*. British Journal of Sports Medicine*, 10. pii: 099131.

Stamatakis, E., Rogers, K., Ding, D., Berrigan, D, Chau, J., Hamer, M. and Bauman (2015) All-cause mortality effects of replacing sedentary time with physical activity and sleeping using an isotemporal substitution model: a prospective study of 201,129 mid-aged and older adults. *International Journal of Behavioral Nutrition and Physical Activity* **12,** 121 (2015).

Tremblay, M., Aubert, S., Barnes, J.D., Saunders, T., Carson, V., Latimer-Cheung, A.E., Chastin, S., Altenburg, T.M., Chinapaw, M.J.M. (2017) Sedentary Behaviour Research Network (SBRN) – Terminology Consensus Project process and outcome, *International Journal of Behavioural Nutrition and Physical Activity,* 14:75.

United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Ageing 2017 - Highlights (ST/ESA/SER.A/397). Available from https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2017_Highlights.pdf. Accessed 18/08/2019.

Wei, J., Xie, L., Song, S., Wang, T. and Li, C. (2019) Isotemporal Substitution Modeling on Sedentary Behaviors and Physical Activity with Depressive Symptoms among Older Adults in the U.S.: The National Health and Nutrition Examination Survey, 2007-2016. Available from: https://www.researchgate.net/publication/334267759_Isotemporal_Substitution_Modeling_on_Sedentary_Behaviors_and_Physical_Activity_with_Depressive_Symptoms_among_Older_Adults_in_the_US_The_National_Health_and_Nutrition_Examination_Survey_2007-2016 [accessed Feb 11 2020].

White, I., Smith, L., Aggio, D., Shankar, S., Begum, S., Metei, R., Fox, K.R., Hamer, M., Iliffe, S., Jefferis, B., Tyler, N. and Gardiner, B. (2017) On Your Feet To Earn Your Seat: pilot RCT of a theory-based sedentary behaviour reduction intervention for older adults*. Pilot and Feasibility Studies* 3:23.

Winkler, E.A.H., Bodicoat, D.H., Healy, G., Bakrania, K., Yates, T., Owen, N., Dunstan, D.W. and Edwardson, C.L. (2016) Identifying adults' valid waking wear time by automated estimation in activPal data collected with a 24hr wear protocol. *Physiological Measurement* 37:1653-1668.

Winter, DA. (1995) *ABC: Anatomy, Biomechanics and control of balance during standing and walking.* Waterloo, Ont: Waterloo Biomechanics.

Wirth, K., Klenk, J., Brefka, S., Dallmeier, D., Faehling, K., Roqué I Figuls, M., Tully, M., Giné-Garriga, M., Caserotti, P., Salvá, A., Rothenbacher, D., Denkinger, M., Stubbs, B. (2016) Biomarkers assocated with sedentary behaviour in older adults: A systematic review. *Ageing Research Reviews* 35 (2017) 87-111.

World Health Organisation (2008) Global Report on Falls Prevention in Older Age. World Health Organisation: Centre of Human Development, Kobe. Available from: https://extranet.who.int/agefriendlyworld/wp-content/uploads/2014/06/WHo-Global-report-on-falls-prevention-in-older-age.pdf Accessed 19/01/2020.

World Health Organisation (2015a) World Atlas of Ageing. World Health Organisation: Centre of Human Development, Kobe. Available from: https://apps.who.int/iris/bitstream/handle/10665/186463/9789240694811_eng.pdf;jsessionid=9592C3A1DF73BE76BB2F91E3219D6A9E?sequence=1 Accessed 19/01/2020.

World Health Organisation (2015b) World Report on Ageing and Health, WHO Press, Geneva, Switzerland. Available from: https://apps.who.int/iris/bitstream/handle/10665/186463/9789240694811_eng.pdf;jsessionid=D475F3BD5A0170CB7D24151A7E7D36E9?sequence=1 Accessed 27/11/2019.

World Health Organization (2018a) Physical activity - Fact sheet N°385. Available from: https://www.who.int/news-room/fact-sheets/detail/physical-activity. Accessed 04/12/2019.

World Health Organization (2018b) Global action plan on physical activity 2018-2030: more active people for a healthier world. World Health Organization. Available from: https://apps.who.int/iris/bitstream/handle/10665/272722/9789241514187-eng.pdf. Accessed 15/11/2019.

World Health Organisation (2019) The Decade of Healthy Ageing, Ageing and Lifecourse, Available from who.int/ageing/en/. Accessed 27/11/2019.

World Health Organisation (2020) Depression. Key Facts. Available from: https://www.who.int/news-room/fact-sheets/detail/depression. Accessed 09/02/2020.

World Health Organisation (2020) WHO guidelines on physical activity and sedentary behaviour. Available from: https://www.who.int/publications/i/item/9789240015128. Accessed 10/12/2020.

Wullems, J.A., Vewrschueren, S.M.P., Degens, H., Morse, C.I., Onambélé (2016) A review of the assessment and prevalence of sedentarism in older adults, its physiology/health impact and non-exercise mobility counter-measures. *Biogerentology* 17:547-565.

Yarnall, A.J., Sayer, A., Clegg, A., Rockwood, K., Parker, S. and Hindle, J.V. (2017) New horizons in multimorbidity in older adults. *Age and Ageing*, 46: 882–888.

Yerrakalva, D., Wijndaele, K., Hajna, S., Westgate, K., Khaw, K.T., Wareham, N., Griffin, S.J. and Brage S. (2019) Do older English adults exhibit day-to-day compensation in sedentary time and in prolonged sedentary bouts? An EPIC-Norfolk cohort analysis. *PLoS One*, 25; 14(10):e0224225.

Wu,Y.T., Fratiglioni, L. Matthews, F.E., Lobo, A., Breteler, M.M.B., Skoog, I. and Brayne, C. (2016) Dementia in Western Europe: epidemiological evidence and implications for policy making. *The Lancet Neurology*, 15, (1), 116-124.

Zhao, Y. and Chung, P.K. (2016) Differences in Functional Fitness Among Older Adults With and Without Risk of Falling. *Asian Nursing Research*, 10(1):51-55

Appendices

Appendix 1 Ethical Approval For Cross-Sectional Study

University of ULSTER

Shore Road
Newtownabbey
County Antrim
BT37 0QB
Northern Ireland

T: +44 (0)28 9036 6552/6518/6629
F: +44 (0)28 9036 6479
www.ulster.ac.uk

Research Office

Our Ref: NC:GOV

12 November 2014

Prof M Murphy
Ulster Sports Academy
University of Ulster
Jordanstown

Dear Professor Murphy

Research Governance Reference Number: 14/0099
Student: Michael McCorry
Supervisors: Prof M Murphy

Title: The effect of physical activity and sedentary behaviours on physical impairment in the elderly

The Research Governance section has been advised that the above application has been considered by your School Research Governance filter committee and the decision of the committee is that the research should proceed.

The committee's decision is valid for a period of three years from today's date (this means that the research should be completed by that date). If you require this period to be extended, please contact the Research Governance section.

Further details of the University's policy are available at www.ulster.ac.uk/research/rg along with guidance notes, procedures, terms of reference and forms.

If you need any further information or clarification of any points, please do not hesitate to contact me.

Yours sincerely

Nick Curry
Senior Administrative Officer
Research Governance
028 9036 6629
n.curry@ulster.ac.uk

BELFAST ■ COLERAINE ■ JORDANSTOWN ■ MAGEE

Appendix 2 Proposed Recruitment Information Sheet/ Email

Volunteers Required for Research Project

We are seeking volunteers to take part in a research project conducted by the Sport and Exercise Sciences Research Institute at University of Ulster, Jordanstown.

You are invited to volunteer if:

- You are a healthy, independent, community dwelling adult aged 70-79 years.
- You have no outstanding medical or physical ailments that might preclude you from completing moderate intensity exercise.

What Will be Involved in The Study

- You will be asked to visit one of the participating centres (Banbridge Parish Centre, Banbridge Leisure centre or Lurgan Leisure centre on two occasions, for approximately one and a half hours on each occasion.
- During the first visit you will complete health declaration and consent forms related to the study. You will be required to answer some questions relating to your lifestyle and energy levels and you will be assessed for balance. You will then be fitted with two small devices that monitor how you expend energy throughout the coming week. You will take these devices home and wear them for the next seven days.
- You will need to return one week later for a second assessment and to return the devices. During the second visit you will be warmed up and assessed on your physical ability (to perform the normal activities of daily living) using the Seniors Fitness Test.

If you would like to participate in this study or would like further information, or if you have any questions relating to the study, please contact Michael McCorry at michael.mccorry@dkit.ie.

Appendix 3 Participant Information Sheet

University of ULSTER

The Effect of Physical Activity and Sedentary Behaviours on Functional Impairment in the Elderly

You are being invited to participate in a research study conducted as part of a PhD research project. Before agreeing to participate it is important that you fully understand the purpose of the study and what will be asked of you during your participation. Please read the following information carefully to ensure you understand what is involved. If you have any questions regarding any aspect of the study, please do not hesitate to ask for clarification. Make sure you are happy with the content before deciding whether to participate or not. Thank you for taking the time to consider this invitation.

What Is the Purpose of The Study?

The purpose of this study is to examine the relationship between physical impairment and time spent inactive or in physical activity with people aged 70-79 years years. Approximately 28-35% of people age sixty-five and over fall each year. This figure increases to 32-42% for people age seventy and over. Research shows that there are many benefits to physical activity with ageing. As we grow older and physical activity levels decrease, the activities of daily living become more difficult to perform. Recently, research has begun to examine the impact of sedentary behaviour on normal function with increased age. However we do not yet know whether physical activity level or sedentary behaviour has the greatest impact on normal function and physical impairment. The main aims of the investigation are:

1. To investigate which variable/s (physical activity or sedentary behaviour) is more closely associated with physical impairment in elderly free-living community dwellers.

2. To investigate whether objectively measured sedentary behaviour, independent of physical activity and physical fitness can predict physical impairment

Why Have I Been Chosen?

You have been invited to participate in the study because you are an independent, community dwelling adult aged 70-79 years who is free from medical or musculoskeletal illness or injury that could exempt you from the study. If you are unsure whether you qualify for participation please ask a member of the research team. This study requires a total of 60 participants.

Do I Have To Take Part?

You are under no obligation to participate. It is entirely up to you to decide whether or not to take part. If you decide to take part you will be given an information sheet and asked to sign a consent form. You may decline to participate or withdraw at any stage without giving a reason.

What Will I have To Do If I Take Part?

You will be asked to visit one of the participating centres (Banbridge Parish Centre, Banbridge Leisure Centre or Lurgan Leisure Centre on two separate occasions (one week apart), for approximately one and a half hours on each occasion. The first visit will determine eligibility and if this is satisfactory you will complete a health declaration form, a short questionnaire and consent forms related to the study. Your height and weight will also be recorded and you will be assessed for falls risk using a fourteen item scale measurement known as the Berg Balance Scale). The assessment requires you to perform tasks that replicate many of the physical movements you perform on a daily basis (e.g. sitting from standing, turning around and moving short distances). After testing, you will be provided with two small devices (matchbox size) that monitor how you expend energy throughout the coming week. One is worn on the waist and attached with an elasticated belt; one is worn directly against the skin of the upper thigh and is attached with a gel patch. You will take these devices home and wear them continuously for the next seven days. You will need to return one week later for a second assessment and to return the devices. During the second visit you will be assessed on your functional ability (to perform the normal activities of daily living) using a 7-item test (the Seniors Fitness Test). The tests are:

1. 30-second chair stand: You are required to stand from sitting as many times as possible in 30-seconds.
2. 30-second arm curl: you are required to perform bicep curls for 30-seconds.
3. Body mass index: your height and weight are measured.
4. Chair sit-and-reach: to are required to stretch forward towards your toes while sitting
5. Back scratch: you are required to try to overlap the fingers of each hand behind your back.
6. Up and go test: you are required to stand up from a chair, move around a cone and sit back down again.
7. 6-minute walk: you are required to walk as far as possible in six minutes. The distance you cover will be measured.

Are There Any Potential risks or Disadvantages To Participation?

- You are required to complete a number of physical tasks that may require you to exert more effort than normal. This may lead to some mild fatigue or discomfort. As with all exercise above resting levels, there is an extremely low chance of cardiopulmonary incident. However a defibrillator and trained personnel will be present at the venue to administer first aid should the need arise.
- You may experience some muscular soreness in the days following the assessments. However, an appropriate warm up and cool down will be conducted in an attempt to avoid this adverse effect.
- A localized skin rash may result from the use of the hydrogel patch against the skin. This should not cause any long term skin problems but the patch can be removed if you feel any discomfort.

Benefits of Participation

- You will gain a deeper understanding of the link between functional ability and sedentary behaviour.
- You will be able to compare your score with your peer group and classify your physical functional ability.

What If something Goes Wrong/

Although highly unlikely, in the event that something goes wrong, the University has in place procedures for reporting, investigating, recording and handling adverse events. Participant complaints will be taken seriously and should be made to the Chief Investigator (Professor Marie Murphy) who will take the appropriate course of action.

Will My Participation Be Kept Confidential?

Any personal information or data obtained during data collection will be kept in confidence in accordance with the Data Protection Act (1998). Personal information will be stored in a password protected computer or within a locked filing cabinet at the University. Freedom of information legislation will allow access to certain non-personal or generalized data. If abnormal results are identified the researcher may wish to pass this information on to the participant's General Practitioner, but only after signed consent has been provided.

What Will Happen To The Results Of The Study?

The results of the study will primarily be used to form part of a research degree taken by the investigator. The study will hopefully be published in a peer-reviewed journal at a later date. All identifying factors will have been removed so that there is no way to identify participants.

Who Is Organising and Funding the Research?

The study has been organized by the investigator and a supervisory team. The research is self-funded.

Who Has Reviewed This Study?

The study has been reviewed and approved by the University of Ulster Ethics Committee. In approving this study, the content is deemed ethical and participants will not be subject to any unnecessary risks. If you require further information prior to, during or after the study, please do not hesitate to contact either the chief investigator or University Research Governance.

Investigator Contact Details

Professor Marie Murphy	Dr Chris Bleakley	Dr Jacqueline Mair	MrMichael McCorry
mh.murphy@ulster.ac.uk,	c.bleakly@ulster.ac.uk,	j.mair@ulster.ac.uk,	michael.mccorry@dkit.ie
Tel. 02890 366025	Tel. 028 90366025	Tel. 028 716 75353	Tel. 07735076008

Research Governance Contact: Nick Curry n.curry@ulster.ac.uk Tel. 02890 366629

Appendix 4 PAR-Q

Name: ____

(BLOCK CAPITALS)

Age: _______ yr DOB: _______/________/______ Date: ________/________/_______

Complete by ticking (□) the appropriate box ***Yes*** *or* ***No***

Q1 Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? □

Q2 Do you feel pain or discomfort in your chest when you have to do physical activity? □

Q3 In the past month have you had pain or discomfort in your chest when you are not doing physical activity? □

Q4 Do you lose your balance because of dizziness or do you ever lose consciousness? □

Q5 Do you get breathless on exertion more than others of about your age? □

Q6 Do you suffer from joint pain or severe back pain? □

Q7 Are you taking tablets, capsules, injections, inhalers, or any other medicine or medications? □

Q8 Are you recovering from an illness or operation of any kind? □

Q9 Do you know of any other reason why you should not do physical activity? □

PLEASE TURN OVER AND COMPLETE THE OTHER SIDE

If you answered YES to any of the questions, you must speak to the researcher. S(he) will deal with the matter in the strictest of confidence. If you answered NO to all questions, please sign below and return.

Summary of Discussion/Advice

____
____
____
____

<u>For Official Use Only</u>

Action: Proceed – No Action Required ☐

Proceed With Caution (see advice given) ☐

Do Not Proceed ☐

Referred To: ☐

Medical Adviser ☐

Physiotherapist ☐

General Practitioner

Other Advice ____

Signature Participant: ________________________________

Signature researcher: ________________________________

Date: _______/______/________

Appendix 5 Consent Form

University of ULSTER

The Effect of Physical Activity and Sedentary Behaviours on Physical Impairment in the Elderly

Chief Investigator: Professor Marie Murphy

Please confirm, by marking the boxes that you agree with the following statements:

1. I have been given, read and understood the information sheet for the above study and have received answers to any questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving reason and without my rights being affected in any way. ☐
3. I understand that the researchers will hold all information and data collected during the study and in confidence and that all efforts will be made to ensure that I cannot be identified as a participant in the study (except as might be required by law) and I give permission for the researchers to hold relevant personal data. ☐
4. I agree for the researchers to contact my General Practitioner in the event that the research identifies a potential health concern. ☐
5. I agree to take part in the above study ☐

Name of participant (please print)	Signature	Date (dd/mm/yy)

Name of researcher	Signature	Date (dd/mm/yy)

Appendix 6 The Berg Balance Scale (BBS)

The Berg Balance Scale (BBS) grades a patient's balance and can monitor functional balance over time or evaluate a patient's response to treatment. The BBS is a 14-item assessment. It is performance based and has a scale of 0-4 for each item (higher score for independent performance) with a maximum score of 56.

1. **Sitting to standing**

INSTRUCTIONS: Please stand up. Try not to use your hands for support

4 able to stand without using hands and stabilize independently

3 able to stand independently using hands

2 able to stand using hands after several tries

1 needs minimal aid to stand or to stabilize

0 needs moderate or maximal assist to stand

2. **Standing unsupported**

INSTRUCTIONS: Please stand for two minutes without holding

4 able to stand safely for 2 minutes

3 able to stand for 2 minutes with supervision

2 able to stand for 30 seconds unsupported

1 needs several tries to stand for 30 seconds unsupported

0 unable to stand for 30 seconds unassisted

3. **Sitting with back unsupported but feet supported on floor or on a stool**

INSTRUCTIONS: Please sit with arms folded for 2 minutes

4 able to sit safely and securely for 2 minutes

3 able to sit for 2 minutes under supervision

2 able to sit for 30 seconds

1 able to sit for 10 seconds

0 unable to sit without support for 10 seconds

4. **Standing to sitting**

INSTRUCTIONS: Please sit down

4 sits safely with minimal use of hands

3 controls descent by using hands

2 use back of legs against chair to control descent

1 sits independently but has uncontrolled descent

0 needs assistance to sit

5. **Transfers**

INSTRUCTIONS: Arrange chair(s) for a pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs, (one with and one without armrests), or a bed and a chair.

4 able to transfer safely with minor use of hands

3 able to transfer safely definite need of hands

2 able to transfer with verbal cueing and/or supervision

1 needs one person to assist

0 needs two people to assist or supervise to be safe

6. **Standing unsupported with eyes closed**

INSTRUCTIONS: Please close your eyes and stand still for 10 seconds

4 able to stand 10 seconds safely

3 able to stand 10 seconds with supervision

2 able to stand 3 seconds

1 unable to keep eyes closed 3 seconds but stays steady

0 needs help to keep from falling

7. **Standing unsupported with feet together**

INSTRUCTIONS: Place your feet together and stand without holding

4 able to place feet independently and stand for 1 minute safely

3 able to place feet together and stand for 1 minute with supervision

2 able to place feet together independently to hold for 30 seconds

1 need help to attain position but able to stand 15 seconds feet together

0 needs help to attain position and unable to hold for 15 seconds

8. **Reaching forward with outstretched arm while standing**

INSTRUCTIONS: Lift arm to 90º. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90º. Fingers should not touch the ruler while reaching forward). The recorded measure is the distance forward that the finger reaches while the subject is in the most forward lean position. (When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

4 can reach forward confidentially >25 cm (10 inches)

3 can reach forward >12.5 cm safely (5 inches)

2 can reach forward >5cm safely (2 inches)

1 reaches forward but needs supervision

0 loses balance while trying/requires external support

9. **Pick up object from the floor from a standing position**

INSTRUCTIONS: Pick up the shoe/slipper, which is placed in front of your feet.

4 able to pick up slipper safely and easily

3 able to pick up slipper but needs supervision

2 unable to pick up, reaches 2-5cm (1-2 inches) from slipper, keeps balance

1 unable to pick up and needs supervision while trying

0 unable to try/needs assist to keep from losing balance or falling

10. Turning to look behind over left and right shoulders while standing

INSTRUCTIONS: Turn to look directly behind you over toward left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.

4 looks behind from both sides and weight shifts well

3 looks behind one side only, turn to other side demonstrates less weight shift

2 turns sideways only but maintains balance

1 needs supervision when turning

0 needs assist to keep from losing balance or falling

11. Turn 360 degrees

INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

4 able to turn 360 degrees safely in 4 seconds or less

3 able to turn 360 degrees safely one side only in 4 seconds or less

2 able to turn 360 degrees safely but slowly

1 needs close supervision or verbal cueing

0 needs assistance while turning

12. Placing alternate foot on step or stool while standing unsupported

INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.

4 able to stand independently and safely and complete 8 steps in 20 seconds

3 able to stand independently and complete 8 steps >20 seconds

2 able to complete 4 steps without aid with supervision

1 able to complete >2 steps needs minimal assist

0 needs assistance to keep from falling/unable to try

13. Standing unsupported one foot in front

INSTRUCTIONS: (DEMONSTRATE TO SUBJECT)

Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width)

4 able to place foot tandem independently and hold 30 seconds

3 able to place foot ahead of other independently and hold 30 seconds

2 able to take small step independently and hold 30 seconds

1 needs help to step but can hold 15 seconds

0 loses balance while stepping or standing

14. Standing on one leg

INSTRUCTIONS: Stand on one leg as long as you can without holding.

4 able to lift leg independently and hold >10 seconds

3 able to lift leg independently and hold 5 – 10 seconds

2 able to lift leg independently and hold ≥ 3 seconds

1 tries to lift leg, unable to hold 3 seconds but remains standing independently

0 unable to try or needs assist to prevent fall

TOTAL SCORE **(Maximum = 56)**

Appendix 7 Protocols for the Senior Fitness Test

1. 30-Second Chair Stand Test (to assess lower body strength)

Instruct the participant to sit in the middle of the chair with back straight, feet flat on the floor, and arms crossed at the wrist and held against the chest. On the signal 'Go' the participant rises to a full stand, then returns to a fully seated position. The score is the total number of stands in 30 seconds.

2. 30-Second Arm Curl Test (to assess upper body strength)

Have the participant sit on a chair with back straight and feet flat on the floor, with the dominant side of the body close to the edge of the seat. The weight is held down at the side, perpendicular to the floor, in the dominant hand with a handshake grip. From the down position, as the elbow bends the weight is curled up, with the palm gradually rotating to a facing up position during flexion of the elbow. The weight is returned as the elbow is fully extended down, with the hand returning to a handshake grip. The score is the total number of arm curls in 30 seconds.

3. Body Mass Index

Height and body mass will be determined using a free-standing stadiometer (Holtain Ltd, UK) and standard laboratory scales (Seca Delta, Germany). Height will be recorded without shoes and body mass will be recorded with minimal clothing. BMI = height/mass^2.

4. Chair Sit and Reach Test (to assess lower body flexibility)

The participant sits on the edge of a 43cm chair. The crease between the top of the leg and the buttocks should be even with the front edge of the chair seat. One leg is bent and slightly off to one side with the foot flat on the floor. The other leg is extended as straight as possible in front of the hip. The heel is placed on the floor with foot flexed at approximately 90^0. With arms outstretched and overlapping and middle fingers even, the participant slowly bends forward at the hip joint as far as possible toward or past the toes. If the extended knee starts to bend, ask the participant to move slowly back until the knee is straight. The maximum reach must be held for 2 seconds. The score is the measured distance remaining from the tips of the middle fingers to the toe end of the shoe.

5. **Back Scratch Test (to assess upper body flexibility)**

Participant stands and places the preferred hand over the same shoulder, palm down and fingers extended, reaching down the back as far as possible. The other arm comes around the back of the waist, palm up, reaching up the middle of the back as far as possible in an attempt to touch or overlap the middle fingers of both hands. The score is the measured distance between the tips of the middle fingers.

6. **Up and Go Test (to assess agility and dynamic balance)**

Instruct the participant to sit in the middle of the chair with back straight, feet flat on the floor and hands on the thighs. One foot should be slightly in front of the other, with the torso slightly leaning forward. On the signal 'Go', the participant gets up from the chair, walks as quickly as possible around the other side of the cone and sits down again. The score is the time taken to complete the walk from start to finish.

7. **The 6-Minute Walk Test (to assess aerobic endurance)**

Participants are instructed to walk around a flat rectangular course for 6 minutes as quickly as possible to cover as much distance as possible. The score is the total distance travelled in the 6 minute period.

The course is a 50m rectangle (20m x 5m) marked off in 5m segments. It is located in a well-lit area with a flat, non-slip walking surface. Multiple participants can be assessed at once but the starting times of individual participants are staggered by 10 seconds to encourage individual pacing throughout. Participants are given a stick for each lap they complete and are instructed to stop when the 6-minute time period has elapsed. A time check is provided at the 3-minute mark and the 2-minute mark, and administrators are permitted to provide gentle praise and motivation throughout the test. Participants are permitted to stop and rest, at any time, on chairs provided at the 5m markers around the course but the testing time will continue to run. Fruit juice and water will be made available to drink at any point before, during or afterwards. At the end of the test participants will be instructed to continue to walk slowly to cool down after which they will be accompanied to stretch the lower leg area. Participants can adjust their pace up or down or stop at any time during the test.

Appendix 8 Instructions for Wearing the activPAL

Instructions for wearing the activPAL

An activPAL is a small electronic device used to measure the amount of time you spend in physical activity or sitting/ lying. You will be asked to wear the device continuously for 7 days, only taking it off at when it is at risk of getting wet e.g. in the shower/ bath or when at the swimming pool. **It is not waterproof so please try to avoid getting it wet**

The activPAL will be attached to the front of your thigh by a researcher, using a sticky pad and some medical grade adhesive tape to prevent it falling off. You will be also be given some spare patches and tape in case you need to remove or re-position the device.

You do not need to replace either the stickie or the patch unless you are removing the activPAL for showering, swimming etc. If you do remove the device, throw away the old stickie and patch and apply new ones.

Once you have worn the device for 7 days, the researcher will remove it and you do not need to do anything else, simply have to carry on with your daily activities as normal.

What are the possible side effects of taking part?

When you wear the activPAL, it is attached to your leg using a 'stickie' patch. Each patch is made-up of a water gel and they are skin friendly. The patches can be removed and repositioned on the skin a number of times. Each one will last 1-2 days. The medical patch that covers the activPAL needs to be replaced each time you remove the device to have a shower or go swimming. The skin over which the activPAL is placed should be clean and free from creams or oils and the activPAL should not be placed over broken skin. Please note that in the unlikely event that a skin rash occurs, remove the device and seek medical advice.

Appendix 9 Instructions for Wearing the Actigraph GT3x

What is an Actigraph?

The Actigraph accelerometer is a small electronic device used to measure the amount of time you spend in physical activity. You will be asked to wear the device continuously for 7 days. You should put it on when you wake up in the morning as you get out of bed, and remove it again as you go to bed at night. Also remove the device when it is at risk of getting wet e.g. in the shower/ bath or when at the swimming pool. **It is not fully waterproof so please try to avoid getting it wet.**

The device should be worn for 7 days. Please try to remember to wear it at all times during your waking day. It should be placed on, or very close to, your right hip at the waistband as demonstrated by the researcher and shown below. It can be worn either underneath or on top of your clothes. If you are wearing a belt, clip the elastic band over your belt). Once you have worn the device for 7 days, the researcher will remove it and you do not need to do anything else, simply have to carry on with your daily activities as normal.

You should feel no side effects from wearing this device. If it becomes uncomfortable you can adjust the elastic belt to loosen or tighten it or to move it slightly on your waist. If you have any questions, please contact the researcher on the number provided to you.

Appendix 10 Published Abstract

The Effectiveness of Physical Activity and Sedentary Behaviour Interventions in Altering Sedentary Behaviour Among Older Adults: A Systematic Review.

M. J. McCorry[1], M.H. Murphy[2], C. Bleakley[3], J. Mair[4]

[1]Department of Humanities, Dundalk Institute of Technology, Dublin Rd., Dundalk, Co. Louth; [2]Ulster University Doctoral College, Sport and Exercise Sciences Research Institute, Jordanstown Campus, Shore Road Newtownabbey, Co. Antrim, BT37 OQB; [3]Congdon School of Health Science, High Point University , NC 27282, USA. [4]School of Applied Sciences, Edinburgh Napier University, Sighthill Campus, Sighthill Court, Edinburgh EH11 4BN.

Address for Correspondence: Mr Michael J. McCorry, Department of Humanities, Dundalk Institute of Technology, Dublin Rd., Dundalk, Co. Louth, Republic of Ireland. E-mail: **michael.mccorry@dkit.ie**.

Title and Qualifications: Mr Michael McCorry (MPhil), Professor Marie Murphy (PhD), Dr Chris Bleakley (PhD), Dr Jacqueline Mair (PhD).

Background: Long and frequent bouts of sedentary behaviour (SB) pose a significant risk to health and increase the incidence of hypokinetic diseases and mortality, independent of the risks posed by physical inactivity alone. The aim of this review was to determine the effectiveness of interventions used by researchers in altering SB among adults aged over 60.

Methods: Two independent reviewers used five databases (CINAHL, MEDLINE, EMBASE, PROQUEST and SBRN) to identify intervention studies up to 31st May 2017 with the following inclusion criteria: published in English, participants aged 60 and over, a reported outcome measure of SB (e.g. sitting time, lying or reclining time, screen time). Intervention studies with no reported SB outcome were excluded. Ten studies totalling 1087 participants were included in the qualitative synthesis (Cochrane Collaboration's Tool for assessing Risk of Bias).

Findings: The methodological quality of interventions was generally poor, and most were pre-experimental or pilot studies. Homogeneity in study design was low. SB was measured objectively and subjectively in a wide range of physical activity and behaviour change interventions. Reduced SB (ranging from 3-137 $min.day^{-1}$) was reported for all interventions (ranging from one week to six months). Statistical heterogeneity was high but data were

pooled from two studies showing a small effect in favour of the treatment group (SMD 0.3; 95% CIs 0.3 to 0.8). There was some positive evidence for interventions that used behaviour change techniques to reduce sedentary behaviour.

Interpretation: There is insufficient evidence to determine the most effective means of targeting SB in this cohort though multicomponent approaches that combine behaviour change with SB or PA designs are currently favoured by researchers. Issues to be resolved include agreement on the measurement tools used to record SB and optimum duration of SB interventions. Future research should include longitudinal studies with extended follow-up periods and those that seek to accurately identify the duration and quantity of sedentary bouts that are harmful to health. Due to the complex nature of sedentarism, the categorising, sub-dividing and specific targeting of behaviours appears to be a key ingredient in designing SB reduction interventions among this cohort.

Source of funding: None**.**

Stage of career: Early career researcher.

No author on this paper holds any competing interests.

Author contributions:

M McCorry: Study design, literature search, data extraction, quality assessment, data analysis, data interpretation

M.H. Murphy: Study design, data extraction, quality assessment, data analysis, data interpretation

C. Bleakley: Study design, data extraction, quality assessment, data analysis, data interpretation

J. Mair: Study design, data extraction, quality assessment, data analysis, data interpretation.

Medline (ovid) Search Strategy

Search No.	Keyword/s	References obtained
#1	Sedentary (keyword)	18731
#2	Sedentary lifestyle (MeSH)	3325
#3	Sitting (keyword)	14494
#4	Inactivity (keyword)	9080
#5	Screen time (keyword)	529
#6	Computer time (keyword)	253
#7	Television (MeSH)	11928
#8	Television (keyword)	16643
#9	Screentime (1 word, keyword)	4
#10	#1 - #9 [OR]	56845
#11	Motor activity (MeSH)	84014
#12	Physical activity (keyword)	56677
#13	Exercise (MeSH)	71278
#14	Activities of daily living (MeSH)	53775
#15	Postural balance (MeSH)	16186
#16	#11 - #15 [OR]	242531
#17	#10 [AND] #16	15193
#18	Old (keyword)	698566
#19	Older (keyword)	264394
#20	Aged (MeSH)	243055
#21	Elderly (keyword)	175054
#22	Senior (keyword)	19915
#23	#18 - #22	3141511
#24	#17 [AND] #23	5476
#25	Limit to Eng. lang. & human	5097

Appendix 11 Standardised Headings for Data Extraction

Date of Extraction
Author Article Title
Year
Country of Origin
Number of participants
Gender Age
Ethnicity
Level of Education
Socioeconomic Status
Employment status
Marital Status
Alcohol/Smoking
Selection Criteria
Exclusions
Disease characteristics
Co-morbidites
Baseline Health
Ethical Approval
Aims and objectives
Design Intervention and Setting
Follow up Duration
Sample size calculation
Outcome Measures
Primary or Secondary
Definition
Measurement tool
Unit of Assessment
Properties of the measure
Follow up - length, number of times
Determinants investigated or discovered
Category
Statistical techniques used
Type of analysis used
Results of analysis
Total SB per week
Subgroup analysis performed
Results support conclusions
Limitations Reported

Appendix 12 Risk of Bias Table for Systematic Review

Authors	Title	Sequence Generation:	Allocation Concealment	Blinding of participants, personnel and outcome assessors	Incomplete Outcome Data:	Selective Outcome Reporting:	Control Group	Subjective Measures	Baseline Imbalances
Paw,CA, vanPoppel, MNM, van Mechelen, W.	Effects of resistance and functional skills training on habitual activity and constipation among older adults living in long-term care facilities: a randomised controlled trial.	**Low risk** Computer random sequence generation was used to determine order of screening.	**Unclear** 'Random' assignment of participants to groups took place after baseline assessment but method is not described. Insufficient information to permit judgement of 'yes' or 'no'.	**Low risk** Research assistants collecting data were blinded to group assignment	**High Risk** High dropout rates from study (30%, 27% and 21% from three elements respectively)	**Unclear** No separate study protocol is available so there is insufficient evidence to permit judgement of 'yes' or 'no'.	**Low risk.** The study appears to be free from other sources of bias.	**Low Risk** Objective Measures of SB used	**Unclear** Authors did not report on significance between demographic variables (more females than males in each group) plus differences in total daily PA between groups
Gardiner, PA, Eakin, EG, Genevieve, NH, Healy, N, Owen, N.	Feasibility of Reducing Older Adults' Sedentary Time	**High Risk** Insufficient information provided. Single group pre- post-design	**High Risk** Insufficient information provided	**High Risk** Insufficient information provided	**Low risk** No missng outcome data.	**Unclear** There is insufficient evidence to permit judgement of 'yes' or 'no'.	**High risk** No control group therefore reporting bias may be present.	**Low Risk** Objective Measures of SB used	**N/A** Single group pre- post-design study,

MacMillan, F, Fitzsimons, C., Black, K., Granat, M., Grant, MP., Grealy, M., Macdonald, H., McConnachie, A., Rowe, d., Shaw, R., Skelton, D., Mutrie, N.	Increasing older adults' walking through primary care: results of a pilot randomised controlled trial	**Low risk** Computer random sequence generation was used to determine order of screening.	**Low Risk** Insufficient information to permit judgement of 'yes' or 'no'.	**High risk** Knowledge of the allocated intervention was not prevented during the study	**High Risk** Dropout. 4 participants from 21 lost from delayed intervention group.	**Low risk** Study protocol is available and all pre-specified outcomes have been reported in the pre-specified way.	**Low risk.** The study appears to be free from other sources of bias.	**Low Risk** Objective Measures of SB used	**Low risk**. Authors report no significant difference in demographic variables between groups.
Chang, AK, Fritschi, C, Kim, MJ	Sedentary Behaviour, Physical Activity, and Psychological Health of Korean Older Adults with Hypertension	**High risk** Participants recruited from older adults registered at one public health centre and given the choice between intervention and control	**High Risk** Participants' allocation to intervention or control groups was not concealed and this knowledge was available to both participants and investigators	**High risk** No blinding and the outcome or outcome measurement is likely to be influenced by lack of blinding	**Unclear** No missing outcome data. Authors state that 48 individuals met inclusion criteria and 48 participants completed the study. Unclear whether there was any movement mid study.	**Unclear** There is insufficient evidence to permit judgement of 'yes' or 'no'.(No study protocol available)	**Low Risk** Study was free from other potential sources of bias	**High risk.** Use of subjective measures of SB may introduce detection bias.	**Low risk** Experimental group contained 29% more participants and 40% more females than Control Group but characteristics were similar
Burke, L, Lee, AH, Jancey, J, Xiang, L, Kerr, DA, Howat, PA, Hills, AP, Anderson, AS.	Physical activity and nutritional behavioural outcomes of a home-based intervention program for seniors: a	**Low risk** A stratified random sampling procedure was used. 60 suburbs within the Perth area	**Unclear** Suburbs were assigned to intervention or control groups using a table of random numbers but	**High risk** Participants and key study personnel were not blinded, and the non-blinding of others was likely to introduce bias	**High risk** 72 participants in the intervention group discontinued the study. 31 participants in	**Low risk** The study protocol is available and all of the study's pre-specified outcomes	**Low Risk.** Study was free from other potential sources of bias	**High risk.** Use of subjective measures of SB may introduce detection bias.	**Low risk** Participants reported to be similar in demographics and lifestyle at baseline

	randomised controlled trial	assigned to intervention or control groups using a table of random numbers	offsite randomisation would have been important here		the control group discontinued the study.	that are of interest in the review have been reported in the pre-specified way.			
Fitzsimons, CF, Kirk, A, Baker, G, Michie, F, Kane, C, Mutrie, N	Using an individualised consultation and activPal feedback to reduce sedentary time in older Scottish adults: Results of a feasibility and pilot study	**High risk** A convenience sample of friends and family was used for this study. Pre-post- design, single group study.	**High risk** Allocation to intervention and control groups was not concealed from investigators or participants.	**High risk** Knowledge of the allocated intervention was not prevented during the study	**Low risk** No missng outcome data and reasons provided for dropout.	**Unclear** There is insufficient evidence to permit judgement of 'yes' or 'no'. (No study protocol available)	**High risk** No control group. There is a chance that other forms of bias may be present in this study.	**Low Risk** Objective Measures of SB used	**N/A** Single group study, pre-post- design 14 men, 10 women.
Matei, R. Thune-Boyle, I., Hamer, M., Iliffe, S., Fox, K.R., Jefferis, B.J., & Gardiner, B.	Acceptability of a theory-based sedentary behaviour reduction intervention for older adults ('Older Your Feet to Earn Your Seat')	**High risk** Sequence allocation was not random. Participants chosen from sheltered housing for group A and community centres for Group B	**High Risk** Allocation to intervention was not concealed from researchers.	**High Risk** Neither researchers nor particpants were not blinded to intervention	**Low Risk** 92% of participants returned data	**Low Risk** The study protocol is available and all pre-specified outcomes have been reported in the pre-specified way.	**High Risk** No control group was used in this study	**High risk.** Use of subjective measures of SB may introduce detection bias.	**High Risk** Decisions were made on the assumption of baseline differences that were not accurate

Sjogren, P., Fisher, R., Kalings, L., Svenson, U., Roos, G., Hellenius, ML.	Stand up for health - avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people.	**High risk** Sequence allocation was not random. Every 3rd man and woman born between 1937-1938 in Stockholm was invited to participate	**High risk** Allocation to interventon or control was not concealed from researchers.	**High risk** Researchers were not blinded to allocation or intervention information. Nurses who scheduled study visits and participants were blind to interventions. .	**Low Risk** No missing outcome data	**Low risk** The study protocol is available and all pre-specified outcomes have been reported in the pre-specified way.	**Low risk** The study appears to be free from other sources of bias.	**High risk.** Use of subjective measures of SB may introduce detection bias.	**Low Risk** Control group 54, intervention 47, Similar profiles but authors did not comment on this so assessment is subjective.
Barone Gibbs, B., Brach, J.S., Byard, T., Creasy, S., Kelliann, K.D., McCoy, S., Peluso, A., Rogers, R.J., Rupp, K., Jakicic, J.M.	Reducing Sedentary Behaviour Versus Increasing Moderate to Vigorous Physical Activity in Older Adults: A 12 Week Randomised Clinical Trial.	**Unclear** Sequence allocation was reported as random but no methodology given for this. Married couples randomised at the level of the couple.	**Unclear** Participants were allocated to one of two intervention groups but no further information was provided.	**Unclear** Participants were allocated to intervention groups but no further information was provided on blinding	**Low Risk** Participants completed 95% of intervention contacts and no participant was lost to the intervention	**Unclear** No separate study protocol is available do there is insufficient evidence to permit judgement of 'yes' or 'no'.	**High Risk** No control group was used in this study	**Low risk.** A combination of objective and subjective measures of SB reduce detection bias.	**Low Risk** Authors report that participant characteristics were comparable by group at baseline but significance was not reported.

White, I., Smith, L., Aggio, D., Shankar, S., Begum, S., Matei, R., Fox., K.R., Hamer, M., Iliffe, S., Jefferis, B.J., Tyler, N., Gardner, B.	On Your Feet to Earn Your Seat:pilot RCT of a theory-based sedentary behaviour reduction intervention for older adults	**Low risk** Site specific random number lists, generated by a trial administrator at UCL were used to achieve a 1:1 allocation ratio at each site	**Low Risk** Allocation to intervention group was concealed from researchers	**High risk** Particpants were blinded but researchers were not blinded to the intervention or outcome measures	**Low Risk** 92% intervention group and 94% control group completed the study	**Low risk** The study protocol is available and all pre-specified outcomes that have been reported in the pre-specified way.	**Low Risk** The study seems to be free from other sources of bias		**High Risk** Significance between demographic variables not reported (more females than males in each group) plus differences in total daily physical activity between groups. Large diff in PA per day at baseline
Lewis, L.K., Rowlands, A.V., Gardiner, P.A., Standage, M., English, C., Olds, T.	Small Steps: Preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults.	**High Risk** Participants were volunteers in a single pre-post group design	**High risk** Allocation to interventon or control was not concealed from researchers.	**High risk** Knowledge of the allocated intervention was not prevented during the study	**Low Risk** Incomplete outcome data were included in analysis	**High risk** Study protocol not available. All pre-specified outcomes have been reported in the pre-specified way.	**High Risk** No control group was used in this study	**Low risk.** Use of objective measures of SB avoid detection bias	**N/A** No control group

Fanning J, Porter G, Awick EA, Ehlers DK, Roberts SA, Cooke G, Burzynska AZ, Voss MW, Kramer AF, McAuley E	Small Steps: Preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults.	**Low risk** Stratified randomisation based on age, gender and location using a computer generated management system	**Unclear** Participants were allocated to either intervention or control group but no further information was provided	**Unclear** Participants were allocated to intervention groups but no further information was provided on blinding	**High Risk** Incomplete outcome data were not explained in analysis	**High risk** The study protocol is available and all of pre-specified outcomes that are of interest in the review are not reported in the pre-specified way.	**Low Risk** Included a Control group	**Low risk.** Use of objective measures of SB avoid detection bias	**Low Risk** 77% female but similar profile at baselineacross both groups. Authors did report this.

Appendix 13 Proposed Expression of Interest Flyer

Volunteers Required for Research Study

We are seeking volunteers to take part in a research project conducted by the Sport and Exercise Sciences Research Institute at Ulster University, Jordanstown.

What Is The Purpose of The Study?

The purpose of this study is to measure the amount and context of sedentary behavior experienced by people aged over 65 years. Research shows that as we age, we tend to sit more often and for longer periods at any one time. Physical activity levels also tend to decrease with advancing age, along with our ability to maintain high levels of physical function. Recently, research has begun to examine the impact of increased sedentary behaviour (sitting down and lying down) on normal function with advancing age. However, we do not yet know how much sedentary behaviour reduction is needed to benefit our health

You are invited to volunteer if:

- You are a healthy, independent, community dwelling adult aged 65 or over.
- You have no outstanding medical or physical ailments that might preclude you from completing normal daily activities.

What Will be Involved?

If you wish to volunteer, your community group will be randomly allocated to either an 'intervention' or 'control' group. If you are part of the intervention group, you will be asked to visit your participating community centre each week for twelve weeks and to make some changes to your lifestyle. If you are part of the control group, you will be asked to continue with normal daily activities. You'll be asked to complete a questionnaire and to wear a small device (for seven days) that measures movement and posture, on three occasions during the study.

If you would like further information, or if you have any questions relating to the study, please contact Michael McCorry at michael.mccorry@dkit.ie (00447735076008).

Appendix 14 Ethics Approval for Intervention Study

Ulster University

Ulster University
Shore Road
Newtownabbey
County Antrim
BT37 0QB
Northern Ireland

T: +44 (0)28 9036 6552/6518/6629
ulster.ac.uk

Our Ref: NC:GOV

03 July 2019

Professor M Murphy
Room 14G15
UU Doctoral College
Ulster University
Jordanstown Campus

Dear Professor Murphy

Research Ethics Committee Application Number: REC/19/0031

Study Title: The effect of a sedentary behaviour reduction intervention on sedentary time and sedentary context among adults aged over 65

Thank you for your recent response to matters raised by the committee. This has been considered and the decision of the committee is that the research should proceed.

Please also note the additional documentation relating to research governance and indemnity matters, including the requirements placed upon you as Chief Investigator.

The committee's decision is valid for a period of three years from today's date (this means that the study should be completed by that date). If you require this period to be extended, please contact the Research Governance section.

1. **Please complete and return the Chief Investigator Statement of Compliance prior to commencing the study and keep a copy for your file.**
2. **Please retain all other documents.**

Further details of the University's policy along with guidance notes, procedures, terms of reference and forms are available on the Ulster University Portal.

If you need any further information or clarification of any points, please do not hesitate to contact me.

Yours sincerely

Nick Curry
Head of Research Governance
028 9036 6629
n.curry@ulster.ac.uk

Appendix 15 Participant Information

University of ULSTER

The effect of a sedentary behaviour reduction intervention on sedentary time and sedentary context among adults aged over 65.

You are being invited to participate in a research study conducted as part of a PhD research project. Before agreeing to participate it is important that you fully understand the purpose of the study and what will be asked of you during your participation. Please read the following information carefully to ensure you understand what is involved. If you have any questions regarding any aspect of the study, please do not hesitate to ask for clarification. Make sure you are happy with the content before deciding whether to participate or not. Thank you for taking the time to consider this invitation.

What Is the Purpose of The Study?

The purpose of this study is to measure the amount and context of sedentary behavior experienced by people aged over 65 years. Research shows that as we age, we tend to sit more often and for longer periods at any one time. Physical activity levels also tend to decrease with advancing age, along with our ability to maintain high levels of physical function. Recently, research has begun to examine the impact of increased sedentary behaviour (sitting down and lying down) on normal function with advancing age. However, we do not yet know how much sedentary behaviour reduction is needed to benefit our health.

Why Have I Been Chosen?

You have been invited to participate in the study because you are an independent, community dwelling adult aged over 65 years who is free from medical or musculoskeletal illness or injury that could exempt you from the study. If you are unsure whether you qualify please ask a member of the research team. This study requires a total of 50 participants.

Do I Have To Take Part?

You are under no obligation to participate. It is entirely up to you to decide whether to take part. If you decide to take part, you will be asked to sign a consent form. You may decline to participate or withdraw at any stage without giving a reason.

What Will I have To Do If I Take Part?

A number of community groups are taking part in this study – participants in some groups will take part in an educational programme and some groups will continue with their normal daily activities. The group you are assigned to will be randomly allocated.

You will be asked to attend your community group as normal for twelve weeks. Week1, week 2, week 6 and week 11 will require you to be present for about an hour to enable the researcher to collect some measurement data. The researcher's first visit will determine your eligibility for the study. If this is satisfactory you will complete a health declaration and consent forms. Your height and weight will also be recorded and you will be provided with a small device (matchbox size) that monitors how you expend energy throughout the coming week. It is worn directly against the skin of the upper thigh and is attached with a gel patch and medical tape. You will take the device home and wear it continuously for the next seven days, removing it only when you take a bath or swim. You will need to come back one week later to return the device. During the second visit you will be asked to complete a questionnaire that ask about your activity levels. This process will be repeated twice during the study.

Intervention Group: If your group is randomly chosen to take part in the intervention, you will be asked to participate in an initial classroom-based discussion related to sedentary behaviour and to make some changes to your lifestyle in the coming week. Subsequent sessions will consist of a 15-min group discussion related to sedentary behaviour, with additional suggestions for lifestyle change in the forthcoming week. You will also be asked to complete a diary each week that records any changes in your behaviour. You will be asked to share this information with the researcher and with your group at each meeting during the intervention.

Control Group: If you are randomly selected not to take part in the programme, you will not need to make any changes to your daily routine as a result of this study.

Are There Any Potential risks or Disadvantages To Participation?

If you are part of the intervention group, you will be asked to make some lifestyle changes over the coming weeks that require you to adjust your normal daily activities. There is an extremely low chance of any medical incident, but you may experience some additional mild fatigue. A localized skin rash may result from the use of the hydrogel patch against the skin. This should not cause any long-term skin problems, but the patch can be removed if you feel any discomfort.

Benefits of Participation

You will gain a deeper understanding of the link between health and lifestyle.

What If something Goes Wrong/

Although highly unlikely, in the event that something goes wrong, the University has in place procedures for reporting, investigating, recording and handling adverse events. Participant complaints will be taken seriously and should be made to the Chief Investigator (Professor Marie Murphy) who will take the appropriate course of action.

How will my data be treated and will my participation in this study be kept confidential?

All data collected will be treated with the strictest of confidence, according to the principles outlined in the General Data Protection Regulation (GDPR; 2018). Specifically, data will be securely stored on a password-protected/encrypted device or computer and only the named researchers will have access to this information. The anonymity and privacy of those who participate in the research will be respected. Only necessary/relevant personal information on participants will be kept and this will be held in the strictest of confidence. Anonymous codes will be used to protect your identity, with all identifiable features removed. General information may be made available upon any Freedom of Information (FOI) requests, in accordance with FOI legislation.

Privacy notice and sponsor compliance with GDPR and the Data Protection Act 2018

Ulster University is the sponsor or managing organisation for this study and we will use information gathered from you and/or your records in order to carry it out. We will act as the data controller, which means that we are responsible for looking after your information and using it properly, as stipulated in GDPR and the Data Protection Act 2018.

Ulster University will keep identifiable information about you for 10 years after the study has finished.

You can find out more about how we look after your information at:

https://www.ulster.ac.uk/about/governance/compliance/gdpr

As a university we use personal identifying information to conduct research to review and improve people's health, wellbeing and care, the services they use and our understanding of the world in which we live. As a publicly-funded organisation, we have to ensure that it is in the public interest when we use personal identifying information from people who have agreed to take part in research. This means that when you agree to take part in a study, we will use your data to conduct the research and analyse the information and findings.

We need to manage your information in specific ways in order for the research to be reliable and accurate and therefore your rights to access, change or move your information are limited.

You should note that if you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personal identifying information possible. Health, care and other human research should serve the public interest, which means that we have to demonstrate that our research serves the interests of society as a whole. We do this by following University and appropriate UK policies and codes of practice. The only people in the University who will have access to your personal identifying information will be those who need to contact you for the study or to carry out audits of the research.

If you wish to raise a complaint on how we have handled your personal data, you can contact our Data Protection Officer who will investigate the matter. If you are not satisfied with our response or believe we are processing your personal data in a way that is not lawful you can complain to the Information Commissioner's Office (ICO).

Our Data Protection Officer is Eamon Mullan; you can contact him at e.mullan@ulster.ac.uk. The research participant privacy notice can be found at:

https://www.ulster.ac.uk/about/governance/compliance/gdpr/privacy

What will happen to the results of the study?

The results of this study will be used as part of a research project and will be published and shared with both academic and non-academic audiences. The findings of this research may lead to further research in the area of sedentary behaviour and/or publication in scientific journals and presentation at conferences. All data will be held for 10 years after study completion in accordance with the Research Governance Steering Committee.

Who Is Organising and Funding the Research?

The study has been organized by the investigator and a supervisory team. The research is self-funded.

Who Has Reviewed This Study?

The study has been reviewed and approved by the University of Ulster Ethics Committee. In approving this study, the content is deemed ethical and participants will not be subject to any unnecessary risks. If you require further information prior to, during or after the study, please do not hesitate to contact either the chief investigator or University Research Governance.

Investigator Contact Details

Professor Marie Murphy	Dr Chris Bleakley	Dr Jacqueline Mair
mh.murphy@ulster.ac.uk	cbleakle@highpoint.edu	j.mair@napier.ac.uk
Mr Michael McCorry	michael.mccorry@dkit.ie	(+44) (07735076008

Research Governance Contact

Nick Curry, n.curry@ulster.ac.uk. Tel. 02890 366629

Appendix 16 Consent Form

The effect of a sedentary behaviour reduction intervention on sedentary time and sedentary context among adults aged over 65.

Chief Investigator: Professor Marie Murphy

Additional investigators: Dr Jacqueline Mair, Dr Chris Bleakley, Mr Michael McCorry.

Please confirm, by marking the boxes that you agree with the following statements:

1. I have been given, read and understood the information sheet for the above study and have received answers to any questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving reason and without my rights being affected in any way. ☐

3. I understand that the researchers will hold all information and data collected during the study and in confidence and that all efforts will be made to ensure that I cannot be identified as a participant in the study (except as might be required by law) and I give permission for the researchers to hold relevant personal data. ☐

4. I agree for the researchers to contact my General Practitioner in the event that the research identifies a potential health concern. ☐

5. I agree to take part in the above study ☐

Name of participant (please print)	Signature	Date (dd/mm/yy)
Name of participant (please print)	Signature	Date (dd/mm/yy)

Appendix 17 The Sedentary Behaviour Questionnaire

SEDENTARY BEHAVIOR: Weekday

On a typical WEEKDAY, how much time do you spend (from when you wake up until you go to bed) doing the following?

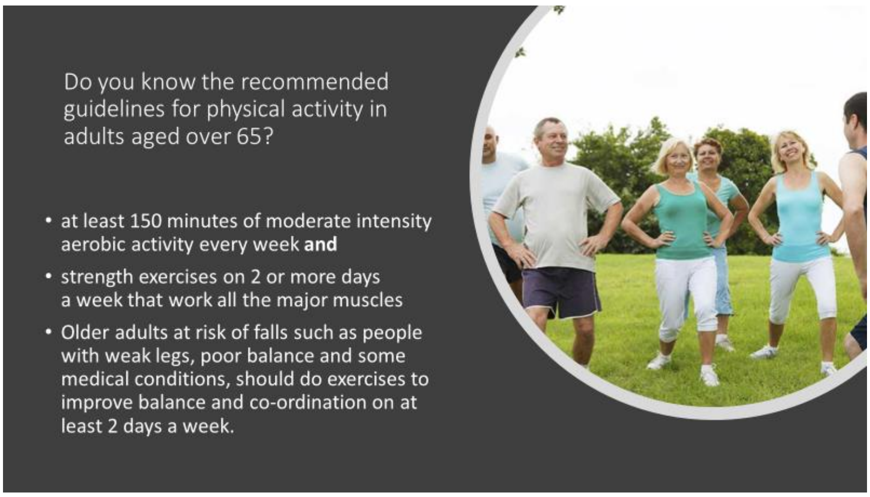
	None	15 min. or less	30 min.	1 hr	2 hrs	3 hrs	4 hrs	5 hrs	6 hrs or more
1. Watching television (including videos on VCR/DVD).									
2. Playing computer or video games.									
3. Sitting listening to music on the radio, tapes, or CDs.									
4. Sitting and talking on the phone.									
5. Doing paperwork or computer work (office work, emails, paying bills, etc.)									
6. Sitting reading a book or magazine.									
7. Playing a musical instrument.									
8. Doing artwork or crafts.									
9. Sitting and driving in a car, bus, or train.									

SEDENTARY BEHAVIOR: Weekend Day

On a typical WEEKEND DAY, how much time do you spend (from when you wake up until you go to bed) doing the following?

	None	15 min. or less	30 min	1 hr	2 hrs	3 hrs	4 hrs	5 hrs	6 hrs or more
1. Watching television (including videos on VCR/DVD).									
2. Playing computer or video games.									
3. Sitting listening to music on the radio, tapes, or CDs.									
4. Sitting and talking on the phone.									
5. Doing paperwork or computer work (office work, emails, paying bills, etc.)									
6. Sitting reading a book or magazine.									
7. Playing a musical instrument.									
8. Doing artwork or crafts.									
9. Sitting and driving in a car, bus, or train.									

Appendix 18 Intervention Presentation to Older Adults



Some facts about sedentary behaviour

- Sedentary behaviours are increasing at all ages worldwide.
- People aged over 60 are the most sedentary members of the population (up to 9.5 hr/day)
- Physical inactivity and sedentary behaviour is the fourth leading cause of death worldwide
- The World Health Organisation recommend breaking up prolonged periods of sitting to improve health.

What is sedentary behaviour?

Any waking activity characterized by very low energy expenditure *and* a sitting, reclining or lying posture.

Why should we sit less?

Too much sedentary time can lead to:

- overweight and obesity
- Cognitive decline
- Loss of bone mineral density
- Risk of falls
- Diabetes
- Cancer
- Cardiovascular disease
- Early death

Is sitting always bad for health?

- Purposeful sitting time that uses cognitive skills e.g. reading, socialising, solving puzzles, is not always bad for your health.
- Time spent sitting/reclining/lying that is not purposeful is thought to be unhealthy.
- The key is to minimise or break up the time you spend sitting, particularly in the afternoons when you are alone.

Some ideas for changes that will make a difference

- avoid long periods sat in front of a TV or computer, particularly in the afternoons
- stand up and move during TV advert breaks
- stand or walk while on the phone
- use the stairs as much as possible
- take up active hobbies such as gardening and DIY
- regularly attend community-based activities
- engage in active play with your grandchildren
- do housework and distribute it throughout the day
- **can you think of any others?**

Are You **STILL** Sitting Comfortably?

Appendix 19 Sedentary Behaviour and Health Tips

University of ULSTER

What is Sedentary Behaviour

Any waking activity characterized by very low energy expenditure while you are sitting, reclining or lying down.

Some Facts about Physical Inactivity and Sedentary Behaviour

- Sedentary behaviours are increasing at all ages worldwide.
- People aged over 60 are the most sedentary members of the population (up to 9.5 hr/day)
- Physical inactivity and sedentary behaviour is the fourth leading cause of death worldwide
- The World Health Organisation recommend breaking up prolonged periods of sitting to improve health.

Too much sedentary time can lead to:

- overweight and obesity
- Cognitive decline
- Loss of bone mineral density
- Risk of falls
- Diabetes
- Cancer
- Cardiovascular disease
- Early death
-

What Can I do To Make a Difference to My Risk Profile?

- avoid long periods sat in front of a TV or computer, particularly in the afternoons
- stand up and move during TV advert breaks
- stand or walk while on the phone

- use the stairs as much as possible
- take up active hobbies such as gardening and DIY
- regularly attend community-based activities
- engage in active play with your grandchildren
- do housework and distribute it throughout the day

Appendix 20 Diary of Sedentary Behaviour Change

Use this diary to record any changes you make to your lifestyle that result in reduced sedentary time. You should aim to make small changes that can be easily accommodated within your current lifestyle. Write down the estimated reduction in sedentary time for each change you record.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Morning							
Afternoon							
Evening							