Analysis of Scottish Health Survey Data to Inform Scottish Physical Activity and Sedentary Behaviour Policy and Surveillance

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Declaration

I declare that this thesis has been composed by myself and that the work has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work which has formed part of jointly-authored publications has been included. My contribution and those of the other authors to this work have been explicitly indicated below. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

Chapter 6:
Strain, T., Fitzsimons, C.F., Foster, C., Mutrie, N., Townsend, N., & Kelly, P. (2016). Age-related comparisons by sex in the domains of aerobic physical activity for adults in Scotland. *Preventive Medicine Reports, 3*, 90-97.

I led all the work on this study, undertook all analyses, and wrote the published paper. Dr Kelly, Dr Fitzsimons, and Prof. Nanette Mutrie MBE assisted in in a supervisory capacity. Prof. Foster and Dr Townsend contributed as authors of a key reference text for this work.

Chapter 7:
Strain, T., Fitzsimons, C.F., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. *BMC Public Health, 16*, 1108.

I led all the work on this study, undertook all analyses, and wrote the published paper. Dr Kelly, Dr Fitzsimons, and Prof. Nanette Mutrie MBE assisted in in a supervisory capacity.

Chapter 8:
Strain, T., Kelly, P., Mutrie, N., & Fitzsimons, C.F. (2017). Differences by age and sex in the sedentary time of adults in Scotland. *Journal of Sports Sciences*, 1-10.

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To my parents, for your unwavering support and interest, no matter how dull my wittering. To Chris, for your positivity. To Bobby, for always saying the right thing.

And to Murray, you're amazing.

Abstract

In 2011, the United Kingdom (U.K.) physical activity (PA) guidelines were updated. The adult moderate-to-vigorous intensity PA (MVPA) recommendation changed to reflect that different frequency and intensity permutations lead to equivalent health benefits. New recommendations were added for muscle strengthening activities (MSA) and the reduction of sedentary time (ST). Those over 65 years were also recommended to undertake balance and co-ordination activities (BCA). Despite these new additions, Scottish PA policy still concentrated on MVPA, with considerable resources allocated to sport and some exercise activities.

Since 2012, the Scottish Health Survey (SHeS) has collected data relating to these new recommendations annually, but few analyses have been undertaken. This thesis contains the most comprehensive analyses of the 2012-15 SHeS PA and ST data to date, and a review into whether the method produces valid and reliable estimates. The aim of this thesis was to inform Scottish PA and sedentary behaviour policy by producing research to support the incorporation of these new recommendations and the promotion of non-sport-related MVPA policies. It also aimed to inform any future developments to PA and ST surveillance in Scotland.

The first three studies of this thesis are cross-sectional analyses of the updated recommendations for adults in Scotland. They present prevalence and participation data in specific domains, activities, and behaviours by age and sex. The main findings were that (1) sport was a minority contributor to the total MVPA of adults in Scotland, regardless of sex, age, or activity status (never more than 20%), (2) compliance with the MSA recommendation was approximately half that of the MVPA recommendation (31% of men and 24% of women), and compliance with the BCA recommendation amongst those over 65 years was very low (19% of older men and 12% of older women), and (3) middle-aged adults in work reported a comparable amount of weekday ST to adults over 75 years (7-8 hours per day).

The fourth study was a review of the available evidence into whether the PA and ST estimates produced by the 2012-15 SHeS were valid and reliable. The SHeS was found to be fit for purpose, but recommendations were made regarding the analysis and interpretation of the data to minimise areas of concern. These were (1) analyse MVPA data with and without the domain of occupational MVPA, (2) make it clear that only sport and exercise activities can contribute to achieving the MSA and BCA recommendations under the SHeS method, and (3) focus on the comparisons between groups in relation to ST, rather than on the absolute values.

The fifth study used the findings from the previous four to inform the design of a prospective cohort study that will investigate the joint effects of MVPA and total ST on all-cause mortality, cardiovascular disease, cancer, and diabetes. This thesis contains the results of the preliminary analyses. This study is designed to inform policy by providing novel information on how the combination of these behaviours affects health outcomes in a representative sample of Scottish adults.

There is clear evidence that this work has already informed policy and surveillance. The work on the relative contribution of the domains of MVPA is regularly cited in evidence briefings for the Scottish Government and the Scottish Parliament. This has increased the awareness amongst key policy-makers that sport is not a major contributor to the total MVPA of adults in Scotland. The work on MSA, BCA, and ST was a catalyst for a proposal to include indicators relating to these recommendations on the national PA monitoring framework. The work on MSA and BCA has also been a key reference text in preparation for the next update to the U.K. PA guidelines, stressing the need to consider surveillance at an early stage. In summary, the novel analyses of SHeS data undertaken for this thesis have demonstrably informed PA and sedentary behaviour policy and surveillance in Scotland.

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Funding

This PhD was funded by a College Research Award from the College of Arts, Humanities and Social Sciences at the University of Edinburgh. This provided three years of funding beginning on the 1st September 2014. I wrote the proposal with Professor Nanette Mutrie MBE and Dr Claire Fitzsimons as supervisors.

Additional internal University of Edinburgh Moray House School of Education (Seedcorn) funding (10 days of researcher time) was sought to carry out work connected to Study 4. Dr Graham Baker was the principal investigator for the connect project, Dr Paul Kelly and I were co-investigators. A clear statement of roles in relation to all the work included in this thesis is given on the declaration page and in the relevant chapters.

Word Count

Abstract, funding, overview:	1000
Main text:	52600
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References:	10600
Tables and figures:	4000
Appendices:	16400

Abbreviations

ACM	All-cause mortality
ACSM	American College of Sports Medicine
ADNFS	Allied Dunbar National Fitness Survey
ASOF	Active Scotland Outcomes Framework
BCA	Balance and co-ordination activity
BMI	Body mass index
CI	Confidence interval
CMO	Chief Medical Officer
CVD	Cardiovascular disease
DIY	Do-it-yourself home maintenance
EF	Edinburgh Framework
GAPA	Global Advocacy for Physical Activity
HEPA Europe	European network for the promotion of Health-Enhancing Physical Activity
HSE	Health Survey for England
ISD	Information Services Division
IPAQ	International Physical Activity Questionnaire
IQR	Interquartile range
ISPAH	International Society for Physical Activity and Health
LMSMA	Let's Make Scotland More Active
MET	Metabolic Equivalents of Task
MSA	Muscle strengthening activity
MVPA	Moderate-to-vigorous physical activity
NHANES	National Health and Nutrition Examination Survey
NHS HS	National Health Service Health Scotland
NCD	Non-communicable disease
PA	Physical Activity
PABAK	Prevalence-adjusted bias-adjusted Kappa
SB	Sedentary behaviour
ScotCen	ScotCen Social Research
sd	Standard deviation
Seniors USP	Seniors – Understanding Sedentary Patterns (a research project)
SDG	Sustainable Development Goal
SHeS	Scottish Health Survey
SHS	Scottish Household Survey
ST	Sedentary time
TV	Television
U.K.	United Kingdom
U.S.	United States (of America)
WHO	World Health Organisation
5x30	30 minutes of at least moderate intensity activity on five days of the week
150 mins	150 minutes of moderate (or 75 minutes of vigorous or an equivalent combination) intensity activity per week

Overview

This thesis is formed of 12 chapters. Chapters 1-5 provide the necessary background and rationale to the thesis aims and objectives. Chapters 6-8 (Studies 1-3 respectively) are descriptive analyses relating to the moderate-to-vigorous physical activity, muscle strengthening and balance and co-ordination activities, and sedentary time of adults in Scotland. These studies have been published in peer-review journals. The chapters follow a similar format of providing additional background and discussion before and after the manuscript including new content as the work progressed and additional content that had to be omitted due to journal word count limits. Chapter 9 (Study 4) concerns the validity and reliability of the results from Studies 1-3. Chapter 10 takes forward points from the first four studies to justify the choice of research objective for Study 5. Chapter 11 (Study 5) includes the preliminary analyses of a prospective cohort study investigating the joint effects of aerobic physical activity and sedentary time of adults in Scotland on non-communicable disease outcomes. Chapter 12 discusses the main themes of this body of work and suggests future directions. A list of publications and presentations of this work is included in Appendix 1.

Chapter 1: Thesis Rationale, Supervision and Timeline

This chapter briefly describes the rationale for this PhD programme of work, explains the supervisory arrangements, and presents the timeline showing when the main studies were undertaken.

1.1 Rationale

In 2011, the four United Kingdom (U.K.) home nations' Chief Medical Officers (CMOs) updated their physical activity (PA) guidelines (Department of Health, 2011). Three years on in 2014, when funding was sought for this PhD programme of work, the guidelines had not been fully integrated with policy in Scotland. New recommendations on muscle strengthening activity (MSA), balance and co-ordination activity (BCA), and sedentary behaviour (SB) were not included in key policy documents. The Scottish Health Survey (SHeS) first included measures of these activities and behaviours in 2012, but few analyses were undertaken (Bromley, 2013; Hinchliffe, 2014).

Instead, Scottish policy focussed on aerobic moderate-to-vigorous physical activity (MVPA) with notable resources allocated to sport. The role of sport in population-level MVPA promotion had been under the microscope in the wake of the 2012 Olympics in London and the 2014 Commonwealth Games in Glasgow. Policy-makers were under some pressure to assess the current priorities (Weed et al., 2012). The international pressure to support unstructured, active lifestyle activities like walking and cycling for transport was getting stronger (Global Advocacy for Physical Activity (GAPA) the Advocacy Council of the International Society for Physical Activity and Health (ISPAH), 2012).

Scottish-specific information was scarce regarding the prevalence and participation levels of contributing behaviours for the new recommendations amongst adults in Scotland. What existed had limitations, which plausibly was why it was not being cited. There was little understanding about how important sport was to the total MVPA of adults in Scotland. This PhD programme of work sought to fill these knowledge gaps by undertaking the most detailed secondary analyses to date of the 2012-15 SHeS PA and ST data, with the aim of informing Scottish policy and future surveillance.

This thesis focussed on adults and older adults as the most significant changes to the 2011 U.K. CMOs' PA guidelines applied to these age groups. The policy and surveillance issues relating to the child guidelines mostly pre-dated the guideline update and have been addressed through separate projects out-with this PhD programme of work (see Appendix 2).

There is a discrepancy in the definitions for the age groups discussed in this thesis between the SHeS (adults: ≥16 years) and the 2011 U.K. CMOs' PA guidelines (adults: 19-64, older adults: ≥65 years). This thesis includes 16-19 year olds to align with standard health behaviour reporting in Scotland. In situations where it is helpful to distinguish between adults and older adults (e.g. Chapter 2), the age boundaries are clearly stated.

1.2 Supervision and PhD Steering Group

In the first year of this PhD, I was jointly supervised by Professor Nanette Mutrie MBE and Dr Claire Fitzsimons. Dr Paul Kelly replaced Professor Nanette Mutrie MBE as co-supervisor in the second and third years due to her phased retirement. All three were based at the Physical Activity for Health Research Centre, University of Edinburgh. A PhD Steering Group was convened soon after commencement to facilitate the interactions with policy-makers and those involved in surveillance. This consisted of:

- Dr Niamh O'Connor, an analyst in the Health and Social Care team at the Scottish Government,
- Dr Catherine Bromley, former Deputy Director of the Scottish Centre for Social Research (ScotCen) who managed the SHeS,
- Professor Nanette Mutrie MBE, a leading academic central in the development of Scottish PA policy over the last two decades, and who continues to be a key intermediary between the research community and the Scottish Government,
- Dr Claire Fitzsimons, a leading academic in the field of SB and was Assistant Director for SPARColl, the collaboration that existed between 2006-2012 to develop the links between PA and health research and policy in Scotland, and
- Dr Paul Kelly, a PA epidemiologist specialising in the measurement of PA.

In Year 2, Dr Niamh O'Connor moved post and her replacement Dr Justine Geyer kindly took on her role in the PhD Steering Group. In Year 3, Ms Julie Guy replaced Dr Justine Geyer in her post at the Scottish Government. The PhD Steering Group met twice in the first year. In the second and third year, there were no formal meetings, but advice was sought on specific relevant issues on an approximately biannual basis.

1.3 Timeline

Figure 1 provides an overview of the timeline of work relating to the five studies in this thesis. From April-July 2016, I paused my PhD to undertake a three-month internship in the Health and Social Care team at the Scottish Government. Whilst there, I undertook a variety of tasks including secondary analysis of PA data from the SHeS and Scottish Household Survey (SHS). Some tasks were somewhat related to work in this thesis; where relevant I have referred to it and included the output as an Appendix.

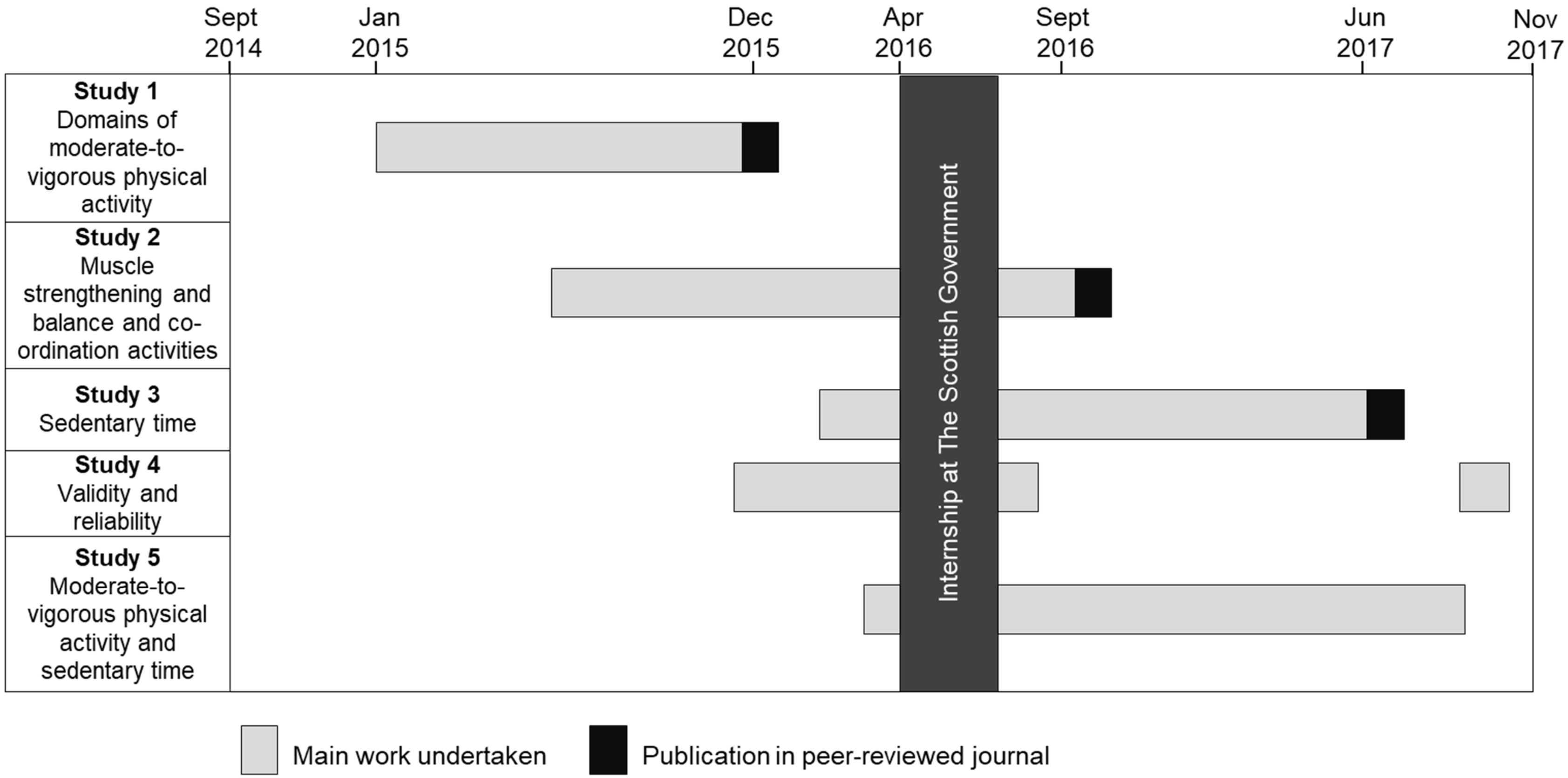

Figure 1. A Timeline of Work Relating to the Five Studies in this Thesis.

Chapter 2: Definition of Concepts

The chapter defines the key concepts that are referred to regularly throughout the thesis. This is necessary because some terms are used differently in the literature and relying on the common usage of some terms could lead to ambiguity.

2.1 Physical Activity and Fitness

PA is ‘any bodily movement produced by skeletal muscles that results in energy expenditure’ (Caspersen, Powell, & Christenson, 1985). Physical fitness is a set of attributes that people have or achieve relating to the ability to perform PA (Caspersen et al., 1985). The health-related attributes of fitness include (1) cardiorespiratory function, (2) muscle function including muscle strength, endurance, and power, (3) metabolic regulation, (4) motor abilities including balance and co-ordination, and (5) morphology (Shephard, 1995). PA can improve attributes of fitness, even when it is not the aim. These ‘behavioural’ definitions are in line with the approach taken by the SHeS.

2.2 Categories of Physical Activity

PA can be categorised by the attribute(s) of health-related physical fitness that it improves. This thesis focusses on three: aerobic activity, MSA, and BCA. They are not mutually exclusive. An activity could be both aerobic and a MSA simultaneously (e.g. cycling) or dependent on the way it was undertaken (e.g. exercises using body weight). In this thesis, the term PA covers all three categories. The specific terms will be used when appropriate.

2.2.1 Aerobic physical activity

Aerobic PA can improve cardiorespiratory fitness (Howley, 2001). It usually involves rhythmic movements of large muscle groups for a sustained duration, increasing heart rate and energy expenditure above the basal metabolic rate (Department of Health, 2011; Howley, 2001). It relies predominantly on aerobic metabolism to provide the necessary energy to the muscles (Physical Activity Guidelines Advisory Committee, 2008). However, if undertaken at a high intensity, then anaerobic metabolism will contribute to some degree. I am aware that using the term ‘aerobic’ is therefore a slight misnomer (Chamari & Padulo, 2015). This is acceptable for the purposes of this thesis as the important point is the potential to lead to cardiorespiratory adaptations.

Multiplying the frequencies, durations, and intensities of relevant activities calculates a total volume for a given time-period. Of these dimensions, intensity is the hardest to measure. It is often expressed in terms of Metabolic Equivalents of Task (METs; Ainsworth et al., 2000). It represents how many times more energy a task requires than sitting quietly (Ainsworth et al., 2000). Data have been used to assign MET values to many activities and behaviours (Ainsworth et al., 2011).

The 2011 U.K. CMOs’ PA guidelines (like most national and international guidelines) use MET values to distinguish between light (1.6-2.9 METs), moderate (3.0-5.9 METs), and vigorous (≥6.0 METs) intensity PA (Department of Health, 2011). This is important because there are different recommendations for different intensities (see Section 3.3.1). The term moderate-to-vigorous PA (MVPA) is used in this thesis to describe all PA ≥3 METs. MVPA usually refers to aerobic PA but it is possible that some non-aerobic MSAs and BCAs are also ≥3 METs. The minor instances where this might affect the SHeS measurement method are discussed in Section 6.7.

2.2.2 Muscle strengthening and balance and co-ordination activities

MSAs can improve skeletal muscle strength and/or endurance if conducted at appropriate frequencies and intensity (Howley, 2001). Balance activities can improve one's ability to withstand challenges from postural sway or destabilising stimuli (Physical Activity Guidelines Advisory Committee, 2008, p. C-2). Co-ordination activities can improve one's ability to use senses such as sight and hearing, together with body parts to perform motor tasks smoothly and accurately (United States (U.S.) Department of Health and Human Services,1996, p. 21).

Frequency, duration, and intensity can also be combined to calculate the total volume of MSAs and BCAs, although other dimensions may better reflect the potential adaptations. For example, the number of repetitions of a movement may be more relevant than total duration (Howley, 2001). The amount of weight moved expressed relative to one's maximal capacity could be a better description of a MSA's relative intensity than a MET value. The equivalent terminology for describing the intensity of BCA has not been developed (Haas et al., 2012). Farlie, Robins, Keating, Molloy, and Haines (2013) describe intensity in this context as the extent to which balance is challenged, although it is rarely assessed.

2.3 The Domains of Physical Activity

PA can be undertaken in a variety of contexts or 'domains', such as work (occupational), around the home and garden (domestic), as transportation, or for leisure (Strath et al., 2013). Academic studies do not always use the same division of domains or sub-domains (Samitz, Egger, & Zwahlen, 2011). The choice may be dependent on factors such as the research question, cultural and contextual factors and/or the measurement instrument used. This thesis uses the term non-occupational MVPA to mean all MVPA undertaken outside of paid or self-employment.

Sport is usually a sub-domain of leisure. It includes PAs with a defined goal where participants adhere to a common set of rules or expectations (Khan et al., 2012). Exercise refers to any PA that is planned, structured, involves repetitive bodily movement with the objective of improving or maintaining physical fitness (Caspersen et al., 1985). It too usually falls under the domain of leisure. PAs can be both sport and exercise activities if they meet the definitions. Many nations have sport-specific policies and funding. The definition of sport in this context may vary between or within country, policy, or organisation. Clarification will be provided when the usage of these terms differs from the definitions provided above.

2.4 Sedentary Behaviour and its Dimensions

SB is defined as any waking behaviour characterised by an energy expenditure of ≤1.5 METs while in a sitting, lying or reclining posture (SB Research Network, 2012; Tremblay et al., 2017). Examples include eating, driving, knitting, reading, desk work, and screen time. Figure 2 shows how the behaviours of PA, SB, and sleep relate to each other in terms of posture and energy expenditure.

Being ‘sedentary’ is distinct from ‘physical inactivity’: the former refers to regularly undertaking prolonged bouts of SB, whilst the latter usually refers non-compliance with the MVPA recommendation (SB Research Network, 2012). As the recommended quantities of MVPA equate to less than 30 minutes per day, it is possible to be ‘aerobically active’ and ‘sedentary’. As a relevant aside, the Scottish Government defines ‘inactive’ as <30 minutes of MVPA per week. Therefore, this thesis uses the term ‘insufficiently active’ to describe all those not meeting the MVPA recommendation.

Total sedentary time (ST) per day or week is just one dimension of SB. The duration of a sedentary bout, and the pattern of interruptions (periods of non-ST in between two sedentary bouts) may also influence health (Tremblay et al., 2017). This thesis uses ST to refer to the total time over a specified period; SB is used to refer to the overall behaviour incorporating both the total time and the patterning.

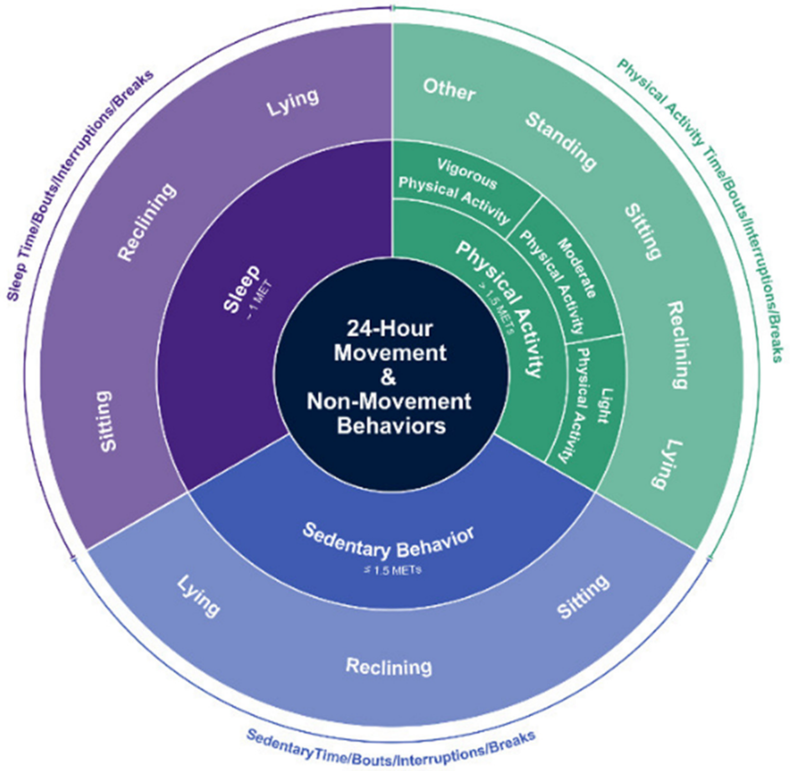

Figure 2. Conceptual Model of Movement-based Terminology Based Around a 24-hour Period.
From Tremblay et al. (2017). The proportion of the space occupied by each behaviour is not prescriptive of the time that should be spent in these behaviours each day. MET = Metabolic Equivalents of Task.

2.5 Policy

There are many definitions of policy; it is broad concept and the periphery is hard to define. I have chosen to use the definition of Milio (2001) as it defines the core principle. “Policy is a guide to action to change what would otherwise occur…Policy sets priorities and guides resource allocation” (Milio, 2001, p. 622).

Examples of PA policies include legislation, guidelines and recommendations, targets, strategies and implementation plans (Bull et al., 2015). Policies can also be set at a local or even organisational level. Monitoring and surveillance systems are technically included under this definition although I will discuss this issue further in Section 12.2.

2.6 Surveillance and Monitoring

In the context of public health, surveillance is defined as the routine tracking of the prevalence of diseases and their risk factors to identify opportunities for prevention (Choi, 2012; Teutsch, 2000, pp. 17-26). Monitoring refers to the routine tracking of priority information (i.e. factors that have been specifically identified) to refine a response (Choi, 2012). One could argue that PA and ST have been identified in the 2011 U.K. CMOs' PA guidelines as priorities (Department of Health, 2011), therefore they are monitored. In Scotland, this monitoring occurs as part of a wider health survey (the SHeS) so one could argue both terms are correct. I have endeavoured to use the most appropriate term for the context.

2.7 Recommendations and Guidelines

In line with the National Institute for Health and Care Excellence (2017), a recommendation is a statement of advice from an authoritative body. Guidelines are a collection of recommendations brought together in one document.

2.8 Indicators and Targets

Indicators are used by the Scottish Government to track progress on an issue of interest, e.g. the levels of compliance with a specific PA recommendation

(The Scottish Government, 2017b). This is different from a target, which is a quantified goal within a specific time-period (Audit Commission, 2003).

2.9 Research

Research is an attempt to derive generalisable and/or transferrable new knowledge by addressing clearly defined questions with systematic, rigorous and repeatable methods (Public Health England, 2015). I use the term academic research to refer to that which is carried out in educational establishments. This distinguishes it from research undertaken by other organisations such as social research companies or a government. This distinction is made to provide clarity when discussing interactions between academic research, policy, and surveillance. Most published academic research has been peer-reviewed. This is an indication of quality control that other publication methods often used by non-academic research do not have. However, as there are many examples of cross-over between research type and publication method, I will ensure clarity on this wherever relevant.

2.10 Method and Measurement Instrument

A typical quantitative study's method comprises of the study design, the measurement method, and the analysis method. Each of these are made up of component stages or decisions, the most important of which are shown in Figure 3. This thesis regularly discusses the impact of these decisions on the results. The term 'measurement instrument' refers to the specific tool used to collect data such as a questionnaire or a device.

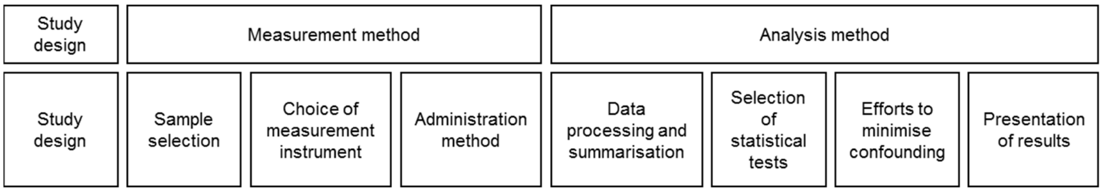

Figure 3. Key Decision-making Stages of a Quantitative Research Study.

2.11 Validity and Reliability

The validity of a measurement is the degree to which it measures what it purports to (International Epidemiological Association, 2014). Reliability is the degree of stability exhibited when a measurement is repeated under identical conditions (International Epidemiological Association, 2014). It is helpful to consider these concepts in terms of their sub-components because this can highlight potential sources of random and/or systematic error. P. Kelly, Fitzsimons, and Baker (2016) developed the Edinburgh Framework (EF) that encourages researchers to think of them as a hierarchical framework (see Figure 4). This framework will be described in greater detail in Section 9.1 but the definitions of the sub-components are provided in Figure 4 as some are referred to in earlier chapters.

Random error is the proportion of variation in a measurement that has no apparent connection to any other measurement or variable (International Epidemiological Association, 2014). Systematic error, or bias, is error that is consistently wrong in a particular direction (International Epidemiological Association, 2014). Study 4 discusses how these sub-components relate to each other; earlier chapters make references to certain sub-components where relevant.

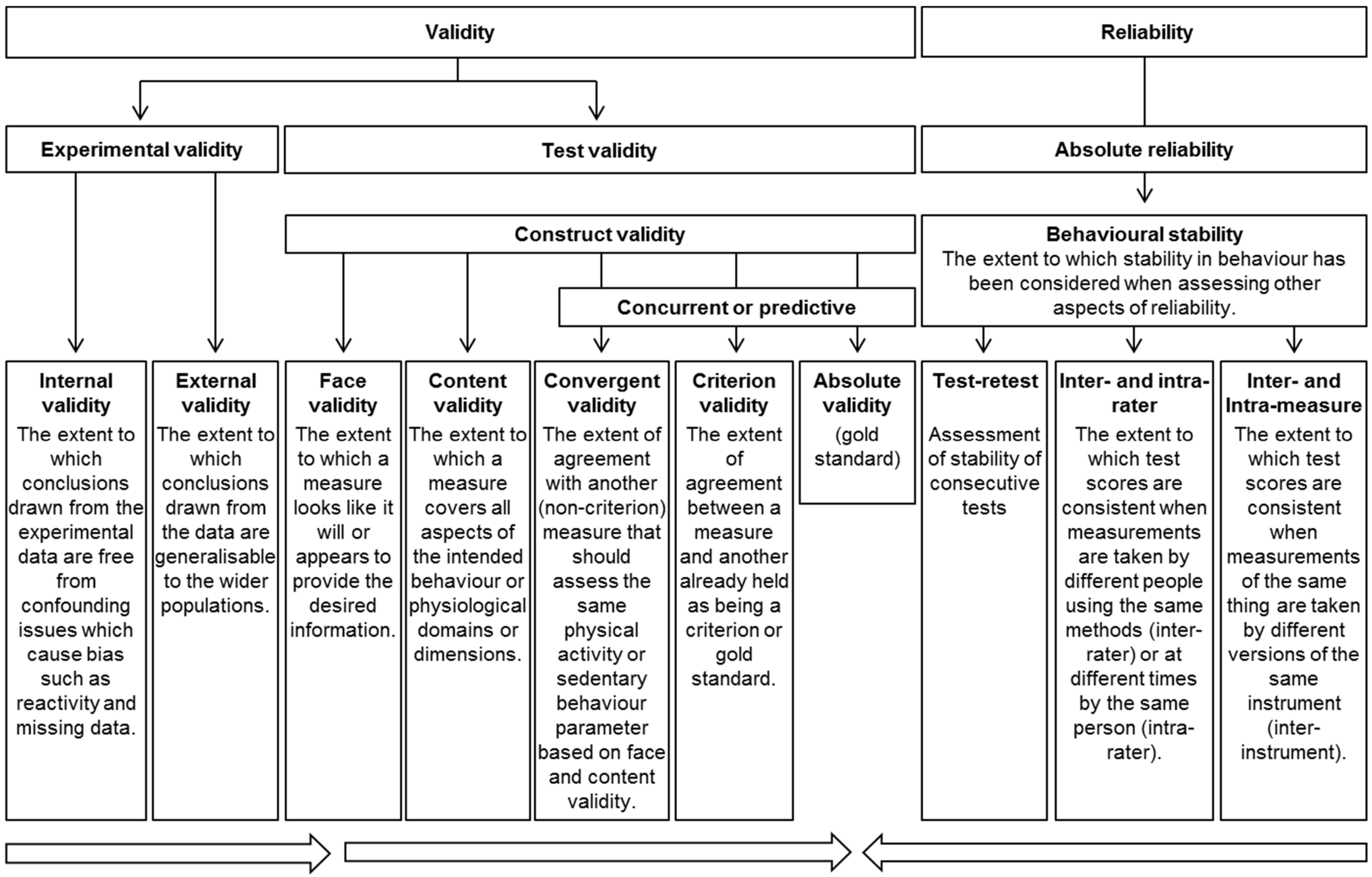

Figure 4. The Edinburgh Framework.

Adapted from P. Kelly et al. (2016).

Chapter 3: Physical Activity and Sedentary Behaviour Guidelines

This chapter describes the evidence behind the 2011 U.K. CMOs' PA guidelines. This is relevant as their interpretation is a reoccurring theme in this thesis. As the 2011 update built upon previous guidelines, it is necessary to include some historical context.

3.1 The Origins of Physical Activity and Sedentary Behaviour Epidemiology

In the 1950s, Professor Jeremy Morris and colleagues compared the coronary heart disease incidence and severity of those with sedentary occupations (bus drivers and mail sorters) with their occupationally more active colleagues (bus conductors and postmen; Morris, Heady, Raffle, Roberts, & Parks, 1953a; Morris, Heady, Raffle, Roberts, & Parks, 1953b). These studies are considered the starting point for the epidemiological evidence base which says movement is beneficial for health.

Over the following 30 to 40 years, the field of PA epidemiology expanded and the association between non-occupational PA and risk of coronary heart disease was established (Powell, Thompson, Caspersen, & Kendrick, 1987). Meanwhile, the American College of Sports Medicine (ACSM) published guidelines on the optimal dose of exercise required to improve cardio-respiratory and muscular fitness (see Haskell, 2008, pp. 283-301). This was based on research on optimising performance. It was not until 1990 that the PA epidemiology evidence was considered and a distinction was made between fitness and health in the guidelines (ACSM, 1990). A paragraph was included that indicated that health benefits could be gained from lower intensity activity than was optimal for improving fitness (ACSM, 1990).

3.2 The 1995 Guidelines for Physical Activity and Public Health

In 1995, the first guidelines for PA and health were published (Pate et al., 1995). They were based on the most comprehensive review of the literature at that time, subsequently published as the Surgeon General's 1996 report (U.S. Department of Health and Human Services, 1996). Adults (no age range given) were recommended to undertake a minimum of 30 minutes of at least moderate intensity aerobic activity on most preferably all, days of the week (Pate et al., 1995). This could be accumulated in bouts of 8-10 minutes. Adults were also recommended to undertake regular MSA; the frequency or other dimensions were not specified (Pate et al., 1995).

Although these guidelines were specifically for Americans, the absence of any global guidelines meant that these were interpreted as such. Many nations, such as the U.K. home nations, developed their own guidelines based on the U.S. Surgeon General's review of the evidence (Department of Health, 2004; Scottish Executive, 2003). In the U.K., the MVPA recommendation was interpreted, monitored and promoted as at least five days per week (Department of Health, 2004; Scottish Executive, 2003); this recommendation (or very similar variations from other nations) will subsequently be referred to as 5x30.

The evidence for the quantified MVPA recommendation was based predominantly on the literature showing beneficial associations between aerobic PA and risk of cardiovascular disease (CVD), even though similar associations had also been found with type 2 diabetes, hypertension, colon cancer, depression and bone health (Folsom, Prineas, Kaye, & Munger, 1990; Helmrich, Ragland, Leung, & Paffenbarger, 1991; Paffenbarger, Lee, & Leung, 1994; Recker et al., 1992; Whittemore et al., 1990). This was because it was the only area with sufficient evidence on which to base a quantified recommendation. Undertaking approximately 30 minutes of moderate intensity non-occupational aerobic PA per day was consistently associated with a 15-30% reduction in the risk of CVD in the study follow-up period[1] compared to the least active groups in the studies (Leon, Connett, Jacobs, & Rauramaa, 1987; Paffenbarger, Hyde, Wing, & Hsieh, 1986; Slattery, Jacobs, & Nichaman, 1989). Although the evidence was compared by calculating average daily volumes, the data were usually collected over a longer (weekly) time frame. This became relevant in the subsequent 2011 update.

Accumulating MVPA through bouts of at least 8-10 minutes was controversial at the time. There were two reasons for the decision. Firstly, the underlying data did not support this patterning and it was fair to assume that the predominant activities of garden work and walking are intermittent in nature (Pate et al., 1995; U.S. Department of Health and Human Services, 1996, p. 148). Secondly, three studies had shown no differential improvements in cardiorespiratory fitness between individuals who were instructed to exercise as a continuous bout or split into short bouts (DeBusk, Stenestrand, Sheehan, & Haskell, 1990; Ebisu, 1985; Jakicic, Wing, Butler, & Robertson, 1995).

There were no specific recommendations for MSA or BCA although both were encouraged (Pate et al., 1995). Most of the research on MSA had been carried out in older age-groups as loss of muscle and bone strength are pertinent issues in this population (U.S. Department of Health and Human Services, 1996, p. 132). Studies had found that regular MSA and BCA were protective against falls and could improve measures of physical function even amongst the very frail (Fiatarone et al., 1994; Tinetti et al., 1994).

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[1] To aid the reader, subsequent references to a reduced risk of death or disease in the study follow-up period will omit the phrase ‘in the study follow-up period’. This is a common convention in the field of epidemiology, despite the technical inaccuracy.

The conclusions of the epidemiological evidence regarding the benefits of MVPA, MSA, and BCA on health outcomes was supported by physiological evidence demonstrating the underlying mechanisms. For full details of evidence at that time see U.S. Department of Health and Human Services (1996), for more recent summaries see Hamer, O'Donovan, and Murphy (2017, pp. 3-18) and Booth, Roberts, Thyfault, Ruegsegger, and Toedebusch (2017).

3.3 Development of the 2011 U.K. Chief Medical Officers' Physical Activity Guidelines

In July 2011, the four home nations' CMOs published 'Start Active, Stay Active', the first U.K.-wide PA guidelines for health (Department of Health, 2011). Expert groups were convened who considered earlier evidence reviews undertaken by the U.S. and Canada to avoid duplication of effort (Kesaniemi, Riddoch, Reeder, Blair, & Sorensen, 2010; Paterson & Warburton, 2010; Physical Activity Guidelines Advisory Committee, 2008; Tremblay, Kho, Tricco, & Duggan, 2010; Warburton, Charlesworth, Ivey, Nettlefold, & Bredin, 2010). In addition, a summary of a series of reviews commissioned by the British Association of Sport and Exercise Sciences (O'Donovan et al., 2010) was considered, alongside any key studies published since. A review on the relationship between SB and obesity was commissioned as part of this process (The SB and Obesity Expert Working Group, 2010). There was also an awareness of the global guidelines that were similar to those of the U.S. and Canada (World Health Organisation (WHO), 2010). Table 1 shows the resultant recommendations for adults (19-64 years) and older adults (≥65 years).

Table 1. The 2011 U.K. Chief Medical Officers' Physical Activity Guidelines

	Age group	
Recommendation	Adults (19-64 years)	Older adults (65+ years)
Moderate-and-vigorous intensity physical activity	Adults should aim to be active daily. Over a week, activity should add up to at least 150 minutes (2½ hours) of moderate intensity activity in bouts of 10 minutes or more (one way to approach this is to do 30 minutes on at least 5 days a week).	Older adults who participate in any amount of physical activity gain some health benefits, including maintenance of good physical and cognitive function. Some physical activity is better than none, and more physical activity provides greater health benefits.
	Alternatively, comparable benefits can be achieved through 75 minutes of vigorous intensity activity spread across the week or a combination of moderate and vigorous intensity activity.	Older adults should aim to be active daily. Over a week, activity should add up to at least 150 minutes (2½ hours) of moderate intensity activity in bouts of 10 minutes or more (one way to approach this is to do 30 minutes on at least 5 days a week).
Muscle strengthening	Adults should also undertake physical activity to improve muscle strength on at least two days a week.	Older adults should also undertake physical activity to improve muscle strength on at least two days a week.
Balance and co-ordination		Older adults at risk of falls should incorporate physical activity to improve balance and co-ordination on at least two days a week.
Sedentary behaviour	All adults should minimise the amount of time spent being sedentary (sitting) for extended periods.	All older adults should minimise the amount of time spent being sedentary (sitting) for extended periods.

Note. From "Start Active, Stay Active", Department of Health (2011) p7.

3.3.2 Moderate-to-vigorous physical activity

There were two changes from the ‘5x30’ MVPA recommendation: (1) removing any frequency requirement, and (2) providing different recommendations for different intensities (see Table 1). There was no change to the overall volume recommended: 150 minutes of moderate intensity activity (150 mins).

Like many of the studies considered for the 1995 U.S. guidelines, the more recent research also measured aerobic PA (sometimes specifically MVPA) over a week e.g. Lee and Paffenbarger (2000); Matthews et al. (2007); Tanasescu et al. (2002). Therefore, the evidence could not support the five-day frequency requirement. One exception to this was Lee, Sesso, Oguma, and Paffenbarger (2004). They compared the risk of all-cause mortality (ACM) between those undertaking aerobic PA on 1-2 and ≥3 days per week. Both groups achieved the equivalent of the total recommended volume (≥1000 kilocalories per week). The authors concluded that there was reduced risk of ACM amongst both groups compared to the least active group (<500 kilocalories per week), with additional benefits for those undertaking activity on ≥3 days (Lee et al., 2004). Other evidence favouring frequent activity included studies demonstrating the positive effect of a single bout on mental well-being and on various CVD risk factors amongst those at risk (Bull & the Expert Working Groups, 2010a). To acknowledge this, the guidelines encouraged adults and older adults to be active daily (Table 1).

There was also substantial evidence that more intense activity conferred additional benefits (Bull & the Expert Working Groups, 2010b). This message had been somewhat lost in the 5x30 recommendation. There was a consistent trend in associations between higher intensity activity and greater risk reductions in ACM, even after adjustment for total volume and other potential confounders (Physical Activity Guidelines Advisory Committee, 2008, p. G2.30). The associations were strongest for cardio-respiratory fitness measures compared to other disease outcomes.

3.3.3 Muscle strengthening activity

Prior to the 2011 guidelines, adults ≥55 years in Scotland were recommended to undertake MSA (combined with BCA) three times a week for health (Scottish Executive, 2003). The 2011 U.K. CMOs' PA guidelines separated out the two activity types, recommended ≥2 sessions per week of each, and extended the MSA recommendation to all adults (Table 1). BCA remained for older adults at risk of falls.

As in 1995, most of the MSA- and BCA-related research focussed on older age-groups (Bull & the Expert Working Groups, 2010a; Paterson & Warburton, 2010).There was strong evidence that regular MSA could maintain or improve functional ability, reduce falls risk, stimulate bone formation and limit age-related loss of bone mass (Bonaiuti et al., 2002; Shea et al., 2004; Sherrington et al., 2008). There were good reasons for extending the recommendations to adults. Muscle and bone mass are thought to peak in the mid-20s (ACSM et al., 2004; Recker et al., 1992). Experimental trials showed that regular MSA participation reduced blood pressure in adults of all ages and improved metabolic control in adults of all ages with type 2 diabetes (see reviews by Cornelissen & Fagard, 2005; Gordon, Benson, Bird, & Fraser, 2009). Furthermore, a prospective cohort study found that regular MSA (specifically weight training for ≥30 minutes per week) was associated with a 23% (95% CI: 2-39%) reduced risk of developing coronary heart disease, adjusted for other activities amongst 40-75 year old men (Tanasescu et al., 2002).

The Technical Report by Bull and the Expert Working Groups (2010a) indicated that there was extensive discussion over this recommendation. One of the main concerns was that the evidence was insufficient to specify dimensions beyond overall frequency. The decision to specify ≥2 sessions per week was based on the exercise physiology research indicating this frequency was sufficient to increase muscle strength (Physical Activity Guidelines Advisory Committee, 2008, p. G5-31). This frequency was compatible with the epidemiological research on health outcomes.

3.3.4 Balance and co-ordination

Prior to the U.K. update, the U.S. and Canada had concluded that there was sufficient evidence that BCA participation could reduce the risk of falls (Paterson & Warburton, 2010; Physical Activity Guidelines Advisory Committee, 2008). This evidence base was strengthened by the publication of a meta-analysis containing 44 randomised controlled trials (Sherrington et al., 2008). The authors concluded that balance-challenging activities were an effective element of a falls prevention programme. However, as with the MSA recommendation, Bull and the Expert Working Groups (2010a) noted the scarce evidence to specify further than ≥2 sessions per week. It is not clear when co-ordination activities were included in this recommendation. Bull and the Expert Working Groups (2010a) do not include this term in their draft report, but the phrase ‘balance and co-ordination’ was used in the previous English guideline document (Department of Health, 2004).

3.3.5 Sedentary behaviour

In 2011, only a few countries’ guidelines (e.g. Austria, Switzerland, Iceland) included a recommendation on SB for adults (Kahlmeier et al., 2015); none provided a quantified recommendation on total ST. (The SB and Obesity Expert Working Group, 2010) advised on the inclusion of a non-quantified recommendation in the

U.K. guidelines for two reasons (1) there was sufficient evidence to indicate a negative relationship between high ST and health outcomes that was independent of MVPA, (2) the indications were that high ST was widely prevalent. A narrative review of SB epidemiology by Tremblay, Colley, Saunders, Healy, and Owen (2010) was a key reference text.

There was substantial evidence to show that high ST was prospectively associated with an increased risk of type 2 diabetes, CVD, some cancers, depressive symptoms, and subsequent weight gain (see Tremblay, Colley, et al., 2010). These associations persisted after MVPA was adjusted for, indicating an independent effect. This distinction between ST and MVPA was supported by studies showing the effect on lipoprotein lipase (an enzyme that regulates blood lipid levels) of hind-limb unloading in rats was not simply the opposite of activity (Hamilton, Hamilton, & Zderic, 2007). There were differences in (1) the muscle regions where enzyme activity increased or decrease, (2) the magnitude of the change (10-fold lower activity levels after inactivity compared to 2.5-fold greater after activity), and (3) the mechanisms of altering activity levels (Hamilton et al., 2007). The paper by Hamilton et al. (2007) provides a good summary of physiological evidence available at the time, Thyfault, Du, Kraus, Levine, and Booth (2015) provide a more recent update. Section 11.1 includes a comprehensive discussion on the interactions of MVPA and ST.

Limitations of this evidence were acknowledged, such as using television (TV) time as a proxy for total ST (The SB and Obesity Expert Working Group, 2010). Consistently stronger negative associations were seen when TV time was the exposure variable, possibly due to unhealthy concurrent behaviours like snacking on calorie-dense food (Williams, Raynor, & Ciccolo, 2008).

(The SB and Obesity Expert Working Group, 2010) felt there was insufficient evidence to make quantified recommendation. The final wording (see Table 1) was such that the emerging evidence on the importance of breaking up ST was acknowledged (e.g. Healy et al., 2008). Section 8.6 discusses whether the decision not to specify a recommended total time is still appropriate.

Regarding the prevalence of total ST, there were no nationally representative data in the U.K. available at the time, although indications were that adults were undertaking potentially harmful levels of ST. For example, the mean reported screen-based entertainment time of adults in Scotland in 2003 was approximately three hours per day (Stamatakis, Hirani, & Rennie, 2009). Objective measurements (heart rate and accelerometry) on smaller samples of English adults found mean total daily ST to be over seven hours (Ekelund, Brage, Besson, Sharp, & Wareham, 2008; Ekelund, Brage, Griffin, Wareham, & the ProActive U.K. Research Group, 2009). The measurement instruments are noted to indicate the heterogeneity of evidence rather than to encourage comparisons (see Section 8.5). Despite these differences, evidence from the U.K. and other nations all concluded similarly: SB was a relevant issue to address in the guidelines (The SB and Obesity Expert Working Group, 2010). In addition, although empirical evidence was scarce, (The SB and Obesity Expert Working Group, 2010) acknowledged the potential implications of technological developments on population levels of ST.

Chapter 4: Policy and Surveillance

This chapter explains why national PA and SB policies are needed. The developments in global policy and advocacy work over the last fifteen years are then discussed as they provide the context to Scottish PA policy over the same period. The chapter finishes with a description of the SHeS, the national PA and ST surveillance method in Scotland that underpins in each of the five studies in this thesis.

4.1 The Need for Physical Activity and Sedentary Behaviour Policy

The right to a standard of living that is adequate for health and well-being is a basic human right (United Nations General Assembly, 1948). Unnecessary ill-health places a burden on society. According to socio-ecological models, policies at all levels can affect an individual's behaviour by interacting with the social, cultural, natural and built environment, as well as individual determinants (Pratt et al., 2015; Sallis et al., 2006).

Insufficient MVPA accounts for between 3.2 and 5.3 million deaths annually, approximately 9% of premature mortality worldwide and 17% in the U.K. (Lee et al., 2012; Lim et al., 2013). The variation in estimates is likely due to differences in method (e.g. combination of data from different sources, adjustment for other health behaviours, categorisation of MVPA levels, and data collection dates; Lee et al., 2013). A recent study estimated the global economic costs of insufficient MVPA to be International-$58.3 billion (Ding, Lawson, et al., 2016). The specific costs to the Scottish economy were estimated to be £94.1 million in 2011, although this was likely conservative as the study only considered certain health conditions (CVD, certain cancers, and diabetes; Foster & Allender, 2012).

There have been no studies of the burden of insufficient participation in MSAs and BCAs, although there are reasons to assume it is considerable. An oft-cited (but hard to verify) statistic is that one-third of community dwelling adults over the age of 65 fall at least once a year (Department of Health, 2011). One of the few studies to consider the burden of high levels of ST estimated that it is responsible for 3.8% of ACM worldwide (433,000 deaths per year), using data from 54 countries (de Rezende et al., 2016). Like insufficient MVPA, the estimate for the U.K. was above the international average at 5.1%.

4.2 The Development of Global Physical Activity Policy

The first 'Global Strategy on Diet, Physical Activity and Health' (WHO, 2004) gave MVPA greater prominence as a health behaviour than it ever had (Bauman & Craig, 2005). However, it was still seen as the secondary risk factor (to diet) in the prevention and management of obesity and the wider benefits were less well acknowledged (Bauman & Craig, 2005).

In 2010, ISPAH launched the Toronto Charter (Bull et al., 2010). This adapted the principles of the Ottawa Charter (where countries committed to promoting population health through cross-sectoral action, creating supportive environments and communities, increasing individual agency, and reorienting health services) to the PA context (WHO, 1986). Alongside it, they released the 'Investments that Work', a guide for nations to prioritise their resources when trying to increase MVPA levels (GAPA, 2012).

In 2013, the WHO set a target to reduce premature mortality from the four main non-communicable diseases (NCDs; CVDs, cancer, diabetes, and chronic respiratory diseases) by 25% by 2025 (WHO, 2013b). This was based on an earlier United Nations resolution (United Nations General Assembly, 2011). Insufficient

MVPA was one of nine risk factors that had a specific target: a 10% relative reduction in its prevalence globally by 2025 (WHO, 2013a). This was notable as MVPA was considered alongside factors such as tobacco, alcohol consumption, and diet that had dominated the NCD health promotion agenda up until this point.

In 2015, the United Nations announced Agenda 2030, an action plan to end poverty, climate change, and fight inequality (United Nations, 2015). Seventeen Sustainable Development Goals (SDGs) formed the framework for action (United Nations, 2015). In 2016, ISPAH launched the Bangkok Declaration which identified the eight SDGs that PA could contribute to, the most obvious being ensuring healthy lives and promoting well-being (ISPAH, 2016). It also reaffirmed links with the 2025 NCD target, setting out six actions points that governments, policy-makers, and stakeholders should promote. There were three of particular relevance to the work in this thesis: (1) renewing commitments to invest in PA policies and implement them at scale, (2) strengthening monitoring and surveillance, and (3) supporting and promoting collaboration, research, and policy evaluation (ISPAH, 2016).

Looking forward, the WHO are currently developing a Global Action Plan on Physical Activity (Foster, Shilton, Westerman, Varney, & Bull, 2017). It builds on the 2013 NCD global action plan (WHO, 2013a), updating the evidence and policy recommendations to maximise the chances of meeting the 2025 goal. It will also take forward the Bangkok Declaration action points, aiming to help nations to bridge the gap between the scientific evidence and their policies, and operationalise their commitments (Foster et al., 2017). It is unclear whether SB will form part of this plan; this is something that will be resolved through consultation. At the time of writing, there are no global strategies that specifically address SB, although there are consensus statements amongst academics to guide future research (Dogra et al., 2017; Tremblay et al., 2017).

4.3 Scottish Physical Activity Policy

Scotland has often been considered as a global leader of PA policy (Bornstein, Pate, & Pratt, 2009), reacting to international policy and advocacy developments and incorporating them at a national level. When health become a devolved issue in 1998 (i.e. controlled by the Scottish Parliament in Holyrood, Edinburgh, rather than through Westminster, London), the opportunity arose to reshape the way Scotland approached PA. A Task Force was set up to develop a national PA strategy, reviewing the scale and consequences on inactivity (Scottish Executive, 2003).

The resultant strategy 'Let's Make Scotland More Active' (LMSMA) was published with cross-party support in 2003 (Scottish Executive, 2003). The overall vision was that "the people of Scotland would enjoy the benefits of having a physically active lifestyle". The recommendations for how to achieve that were consistent with the areas for health promotion identified in the Ottawa Charter (WHO, 1986). The strategy also contained guidelines, heavily based on the 1995 U.S. guidelines (Pate et al., 1995). There was also a target: that 50% of the adult population would meet the stated MVPA guideline (5x30) by the year 2022 (Scottish Executive, 2003). This was based on a 1% increase per year that countries such as Canada and Finland were demonstrating (Barengo, Nissinen, Tuomilehto, & Pekkarinen, 2002; C. L. Craig, Russell, Cameron, & Bauman, 2004). The strategy emphasised that this was the start of a longer-term process requiring continued effort, funding, and resources. To ensure continued focus, a five-year review of the strategy was scheduled for 2008 (Halliday, Mutrie, & Bull, 2013).

Monitoring data indicated that notable progress had been made in the first five years; 46% men and 35% women aged 16-74 met the MVPA guidelines in 2008 compared to 42% and 32% in 2003 respectively (Scottish Physical Activity Research

Collaboration, 2010). Figure 5 provides an overview of the period from 2003 to present. The review concluded that the strategy had led to the successful national co-ordination of government policies (Scottish Physical Activity Research Collaboration, 2009). Age- and sex-specific analysis of the monitoring data identified adults over 65 years and women of all ages as priority areas for policy and resources (Scottish Physical Activity Research Collaboration, 2010).

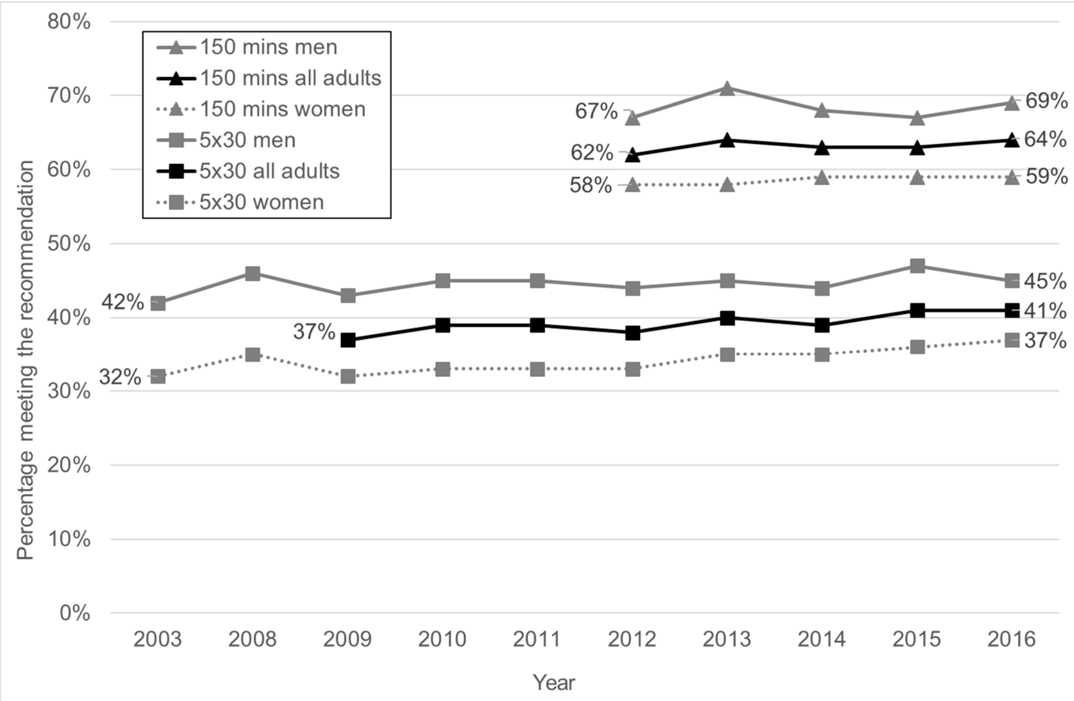

Figure 5. Percentage of Adults in Scotland Meeting the Moderate-to-vigorous Physical Activity Recommendations, 2008-2016.
The 2003 figures include 16-74 year olds only with a minimum bout length of 15 minutes. All other years are for adults ≥16 years with a minimum bout length of 10 minutes. Data obtained from Stamatakis (2004) and Scottish Government (2017).

Over the five years following the launch of LMSMA, the Scottish Government introduced a National Performance Framework to monitor progress across a range of policy areas (The Scottish Government, 2007). The proportion of adults meeting the 5x30 guidelines was included as an indicator that contributed to the strategic objective living ‘longer, healthier lives’ (The Scottish Government, 2007).

In July 2008, Glasgow was awarded the 2014 Commonwealth Games. This changed the context of PA policy in Scotland with most publications in the subsequent six years framed in relation to its ‘Legacy’ (The Scottish Government, 2009). There was a restructure within the Scottish Government and a minister was appointed to oversee the Commonwealth Games, the Legacy project, and sport-related issues (this included PA).

The Legacy had broad aims covering business, connectivity, sustainability and activity, as outlined in the strategy document ‘On Your Marks’ (The Scottish Government, 2009). The absence of evidence showing that a high-level sporting event could boost population MVPA levels was acknowledged, but this did not thwart ambition (The Scottish Government, 2009). MVPA promotion initiatives were to go through local authorities, health boards, sports bodies, voluntary organisations, and businesses, continuing the multi-sectoral nature of previous efforts (The Scottish Government, 2009). Activities such as walking were referred to, although the focus was on sport: developing local club networks, improving facilities, and supporting coach education.

The 2014 implementation plan ‘A More Active Scotland’ aligned with the latest global advocacy work as it set outcomes under areas highlighted in the Toronto Charter and the ‘Investments that Work’: transport and environment, workplace, National Health Service Health Scotland (NHS HS) and social care, education, and sport and recreation (Bull et al., 2010; The Scottish Government, 2014c). Evaluation of these outcomes was set for one, five, and ten years after publication, although many lacked detail regarding their assessment.

Shortly after the 2014 Commonwealth Games, a restructure in the Scottish Government created the Active Scotland Division, who published the Active Scotland Outcomes Framework (ASOF; The Scottish Government, 2014a; Figure

6). There are parallels with the National Performance Framework: broad ‘outcome’ statements with indicators to track progress. The ASOF is the current focus of national Scottish PA policy and is also used as a basis for many local authority PA strategies (e.g. Highland Community Planning Partnership, 2016) and evaluation (e.g. The Scottish Government, 2016a).

The ASOF’s top level indicator was: to increase the proportion of adults meeting the MVPA recommendation. This aligned with the National Performance Framework indicator (see Figure 7). Since 2012, the SHeS has been able to monitor ‘150 mins’ although it can be analysed to track ‘5x30’ too. As Figure 5 showed, there is no evidence to suggest that underlying MVPA levels have changed amongst adults in Scotland between 2008 and 2016. However, it is clear that the change in recommendation has had profound implications on whether the majority of adults in Scotland are viewed as being sufficiently or insufficiently active.

As the ASOF preceded the SDGs no explicit links have been made. There are, however, obvious connections: Aside from the obvious aim of improving good health and well-being, the active travel indicator relates to ‘climate action’, and greenspace accessibility relates to ‘life on land’ (The Scottish Government, 2014a; United Nations, 2015). Furthermore, efforts to reduce inequalities underpin the ASOF (The Scottish Government, 2015).

The ASOF outcomes and indicators do not entirely match that of the implementation plan, nor do they completely align with the 2011 U.K. CMOs’ PA guidelines (see Figure 7). Only indicators relating to MVPA are included. Despite annual data collection on the other recommendations by the SHeS since 2012, there was limited understanding of the prevalence of MSA and BCA participation, and the levels of ST amongst adults in Scotland.

VISION: More people in Scotland are more active, more often

- Proportion meeting the MVPA guidelines

1. We encourage and enable the inactive to be more active	**2. We encourage and enable the active to stay active throughout life**	**3. We develop physical confidence and competence from the earliest age**
• Percentage of inactive adults • Recreational walking participation in adults	• Frequency of sport and exercise participation • Participation in sport, exercise, and walking in adults over 65 years • Attendance at leisure facilities	[All indicators under this outcome relate to children]
4. We improve our active infrastructure – people and places	**5. We support well-being and resilience in communities through physical activity and sport**	**6. We improve opportunities to participate, progress, and achieve in sport**
• Satisfaction with leisure facilities • Greenspace accessibility • Active travel	• Perception of community safety for play • Perception of safety of neighbourhood for walking • Proportion volunteering relating to sports and exercise	• Sports participation • Team Scotland performance

Figure 6. Adult Indicators in the Active Scotland Outcomes Framework.

Adapted from The Scottish Government (2014a).

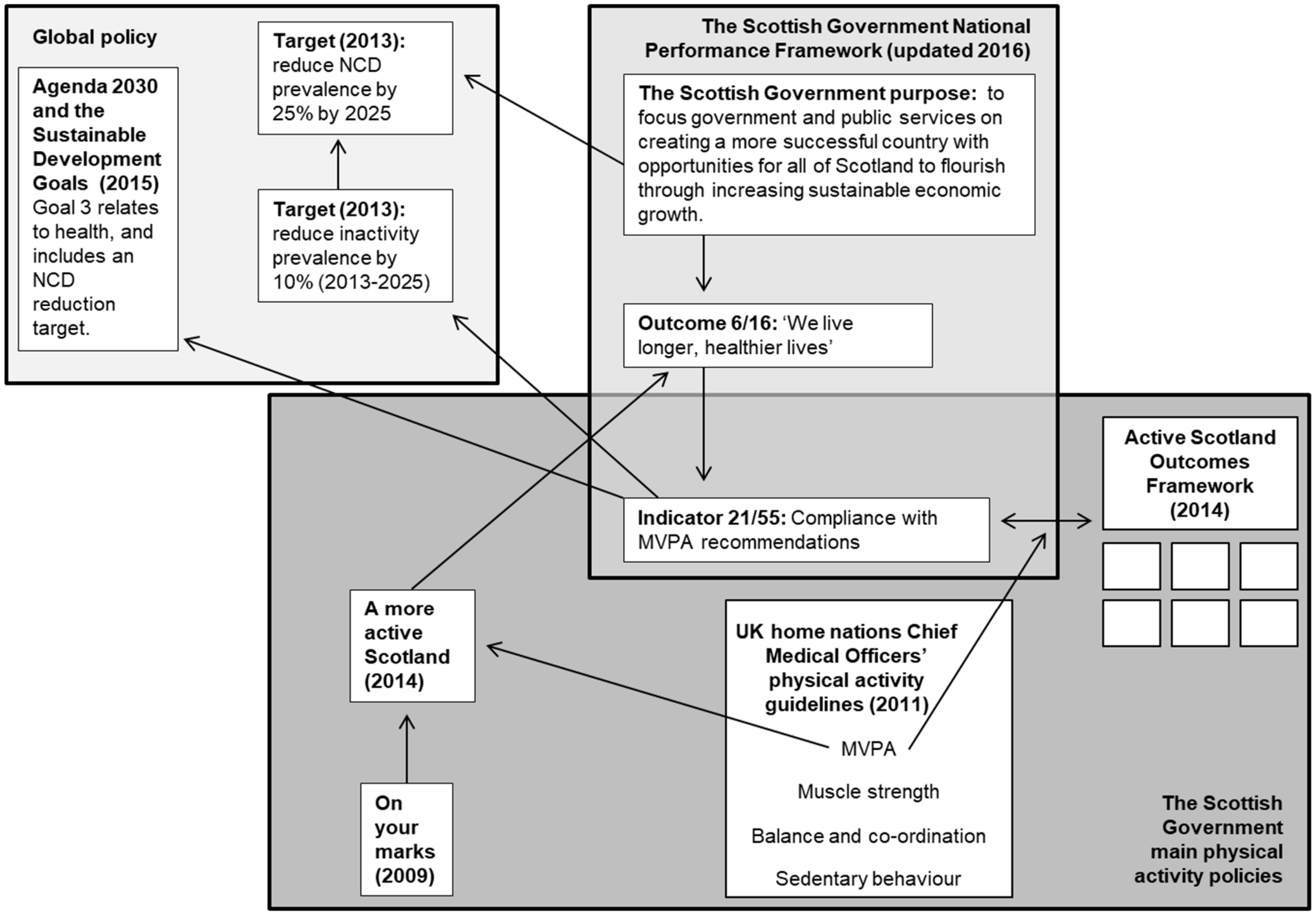

Figure 7. Scottish Physical Activity Policy in a National and Global Context.

Documents referred to from top left, clockwise: United Nations (2015), (WHO, 2013a), The Scottish Government (2016b), The Scottish Government (2014a), Department of Health (2011), The Scottish Government (2009), The Scottish Government (2014c).

As a high-level overview, Figure 7 does not cover the domain-specific strategies that exist or the extent to which they are resourced. When this PhD programme of work was being planned in 2014, walking and active travel strategies had just been published (The Scottish Government, 2014b; Transport Scotland, 2014). However, they seemed to be at odds with the resource allocation. In the 2015-2016 budget, over £68 million was allocated to 'sport and legacy', with £3.3 million allocated to 'PA' (The Scottish Government, 2014d). Although it is likely that some of the healthcare and local authority budgets was spent on non-sport-related PA promotion, it was still appropriate to question whether this was proportionate. However, there was limited high quality evidence to guide what proportions would be appropriate. The areas where policies did not fully align with each other became a focus of the work in this thesis.

4.4 Scottish Health Survey

4.4.1 Overview

The SHeS is one of the longest running PA surveillance systems, and is almost unique in that it has kept the measurement method almost constant over that period. The first survey was in 1995, followed by 1998, 2003, and annually since 2008 (see Appendix 3). The 2012-15 SHeS are the primary data source for this thesis. They were commissioned as a block of four surveys by the Scottish Government Health Directorates and managed by ScotCen. The sample frame included those living in private households in Scotland. The stated aims of the 2012-15 SHeS was to:

1. estimate the prevalence of health conditions, associated risk factors and behaviours,
2. identify differences between regions and other subgroups, and

3. monitor trends (Campbell-Jack & Hinchliffe, 2016).

Summary statistics are published in Annual Reports in the September following the survey year (e.g. Campbell-Jack, Hinchliffe, & Rutherford, 2016). Anonymised datasets are deposited in the U.K. Data Archive a few months later and are available for academic use after agreeing to End User License see Appendix 4. Information Services Division (ISD; a branch of NHS HS) manage the routine linkage of these data to mortality and morbidity records for those that consent (see Appendix 5). There is an approximate time delay of one to two years after survey completion on this process. Data are also used to update the relevant ASOF indicators.

4.4.2 Sampling methods

The 2012-15 SHeS was designed to allow the combination of the annual datasets, increasing the size for subgroup (e.g. Health Board) analyses. The total adult (≥16 years) sample size was 19,365, split relatively evenly between the four years. It was stratified to ensure that each Health Board had a minimum of 125 respondents, although some chose to pay for a ‘boost sample’ which permitted more detailed analysis at that level. The adult response rate was 52-56% (Campbell-Jack & Hinchliffe, 2016).

Households were selected for interview through a two-stage clustered design to reduce fieldwork costs. Addresses taken from the Royal Mail’s Postcode Address File were clustered into geographically close areas. Addresses were selected from a quarter of areas each survey year; all were covered by the end of a four-year cycle. The combined four-year sample is therefore un-clustered in design.

Clustered and stratified samples cannot be analysed in the conventional ways designed for simple random samples because two key assumptions are violated: (1) that each observation has an equal probability of being selected, and (2) that the observations are independent of each other. If ignored, both the value of the estimates and their variance may be affected.

A weighting variable is calculated to adjust for the disproportionate stratification and to account for non-response bias. This process matches the observed sample to known population characteristics including age, sex, and health board population size. This relies on knowing the probability of each household being selected for interview from the Postcode Address File. It is time-consuming and costly but the only way to produce nationally representative estimates. Weights are provided on the datasets stored in the U.K. Data Archive. For full details of the weighting calculations see Campbell-Jack and Hinchliffe (2016).

It is also necessary to adjust variance estimates to counteract the effect of clustering and stratification. Analysing clustered data as if from a simple random sample will usually underestimate the variance. This is because, on average, cases within clusters share more characteristics with each other than those outside it. The effect of disproportionate stratification on the variance could be in either direction and should not be ignored. Incorrectly estimating the variance can lead to Type I or Type II errors.

I have used Taylor Series Linearisation method to adjust the variance estimates in this thesis. In simple terms, it involves modifying the equations normally used to calculate the variance (Heeringa, West, & Berglund, 2010). It tends to be the preferred method if information on the clusters and strata are provided (as is the case in the 2012-15 SHeS). Statistical software (e.g. STATA SE version 14, StataCorp, Texas, U.S.) perform this analysis if it is specified. Alternatives include replication methods or multi-level models. Generally, the estimates derived from Taylor Series Linearisation and replication methods do not differ substantively

(Heeringa et al., 2010). Multi-level models are useful when the effect of the clustering or stratification is of interest; this is not applicable to the analyses in this thesis. It is not possible to use this in combination with all statistical tests, although the range available in STATA is expanding.

4.4.3 Measurement of physical activity

Data on PA and ST were collected through interviewer-led computer assisted interviews, carried out in the respondent's home. The 2012-15 SHeS questionnaire grouped activities into five domains: (1) housework, (2) gardening, heavy manual work, and do-it-yourself (DIY) maintenance, (3) sports and exercise activities, (4) walking, and (5) activity at work (see Appendix 6 for questionnaire).

For (1) and (2), respondents were asked about participation in activities listed on two separate prompt cards with relevant light intensity activities and MVPAs respectively. Respondents reporting participation in any MVPAs were then asked the total frequency in the previous 28 days, and average bout duration. Total weekly duration of domain-specific MVPA was then derived.

For (3), respondents were asked to specify which activities (prompt cards listing 40 alternatives) they participated in over the previous 28 days, the frequency, average bout duration, and whether the effort was usually enough to make them out of breath or sweaty. They were also able to report any activities that were not specifically prompted. Each sport and exercise activity was allocated an intensity (light, moderate, or vigorous) which was based on the MET values from the 2011 Compendium of Physical Activities (Ainsworth et al., 2011). For some activities, their allocated intensity depended on the response to the question that asked if the activity makes them 'breathe faster, feel warmer, or sweat'. A full list of the allocations of the activities is in Appendix 7. The total weekly duration for this domain was then derived for all those considered MVPA. To reflect the recommendation that 75 minutes of vigorous intensity activity would lead to equivalent health benefits of 150 minutes of moderate intensity activity, durations of vigorous intensity activities were doubled.

Respondents were also asked whether the effort of each reported activity was usually enough to make their muscles feel some tension, shake or feel warm. For some activities, this decided whether they were classified as a MSA; others were always MSAs, others never counted (see Appendix 8 for full list). The total weekly frequency of MSAs was derived from the relevant activities. These follow-up questions were added in 2012 in response to the 2011 U.K. CMOs' PA guidelines.

The activity 'exercises' had an additional follow-up question asking whether they involved standing up and moving about. This determined whether it counted as a BCA or not. Other activities were always BCAs, others never counted (see Appendix 8 for full list). The total weekly frequency of BCAs was derived from the relevant activities.

For (4), respondents were asked whether they had walked for at least ten minutes in the previous 28 days, and if so, on how many days, and whether they walked multiple times per day. Average walk duration and usual walking pace were also reported. It was considered of moderate intensity if walking pace was 'brisk' or 'fast'. Those over the age of 65 were asked whether the effort of walking was enough to make them 'breathe faster, feel warmer, or sweat'. If the response was affirmative then their walking was considered of moderate intensity even if the pace reported was 'slow' or 'steady average'. Total weekly duration was derived with a maximum of two walks per day contributing.

For (5), those in employment in the four weeks prior to interview were asked if their job was either (i) very physically active, (ii) fairly physically active, (iii) not very physically active, or (iv) not at all physical active. Only those responding (i) were allocated any MVPA in this domain. This was 20 hours per week for part-time workers and 40 hours per week for full-time employees. The duration of reported ST at work was subtracted from this total. All activity in this domain was considered of moderate intensity. Total minutes of weekly MVPA were calculated by summing totals from the five PA domains.

4.4.4 Measurement of sedentary time in the Scottish Health Survey

After the questions on MVPA, respondents were asked to report their ST in three categories of behaviours: (1) sitting time at work (those in paid or self-employment only) on a typical work day, (2) leisure-time TV or other screen time (e.g. computer, game boy, video game) on weekday and weekend days, (3) any other leisure sitting time (e.g. eating a meal, reading, listening to music) on weekday and weekend days. The summary measures provided on the archived datasets summed (2) and (3) for weekdays and weekend days. Prior to 2012, the SHeS only asked about category (2).

4.4.5 Validity and reliability

There are no published convergent or criterion validity studies for the 2012-15 SHeS (or the preceding years). Authors using the 2003 and 2008 surveys in academic publications often cited studies involving similar but not identical variations of Health Survey for England (e.g. Stamatakis, Hamer, & Dunstan, 2011; Stamatakis, Hamer, & Lawlor, 2009). The 2006 and 2008 HSE questionnaires demonstrated moderate correlations across various summary measures of MVPA and ST when compared against accelerometry (Scholes et al., 2014). Similar conclusions were reached from comparisons between the 2012 HSE and the short-form International Physical Activity Questionnaire (IPAQ; Scholes, Bridges, Ng Fat, & Mindell, 2016). However, these studies have considerable limitations (discussed in more detail in Section 9.4), making the interpretation regarding the validity and reliability of the results from the SHeS difficult.

Detailed reading of the SHeS Technical Reports suggests many steps have been taken to improve the validity and reliability of the surveys' results (Campbell-Jack & Hinchliffe, 2016). For example, interviews are spread throughout the year to minimise bias due to seasonality effects. Interviewers undergo thorough training to ensure consistency and minimise missing data rates. According to the EF, these factors contribute to the internal and external validity of the results, which underpin any convergent or criterion validity tests. Understanding what evidence existed regarding the validity and reliability of the 2012-15 SHeS PA and ST estimates was an objective of this thesis.

Chapter 5: Thesis Aims and Objectives

This chapter presents the aims and objectives of this thesis, based on the knowledge gaps identified in the previous chapter. I describe the rationale for the objectives in relation to the overall aim and the method for tracking progress.

5.1 The Knowledge Gaps, Aims and Objectives

In Section 4.3, I noted two areas of inconsistency within Scottish PA and SB policy in 2014: (1) a mismatch between the strategic documents such as the implementation plan and 'Let's get Scotland Walking' (The Scottish Government, 2014b, 2014c) and the resources allocated to non-sporting MVPA promotion initiatives (The Scottish Government, 2017a), and (2) the absence of MSA, BCA, and SB in the main policies such as the Active Scotland Outcomes Framework and/or the implementation plan (The Scottish Government, 2014a, 2014c) despite their inclusion in the 2011 U.K. CMOs' PA guidelines (Department of Health, 2011). There was a lack of Scottish-specific high quality research on these areas that could be used to challenge the status quo, which plausibly contributed to the situation. Through this PhD programme of work, I sought to address these knowledge gaps by undertaking secondary analysis of SHeS data. Other sources of data were considered but none were suitable (see Appendix 9).

In Section 4.4, I explained how a wide range of evidence existed that might support or refute the validity and reliability of the PA and ST estimates derived from the SHeS. This evidence related to many of the sub-components of validity and reliability, not just the convergent or criterion validity. It was important to understand whether the results reported in this thesis were valid and reliable, so I undertook a review of the evidence. This was chosen over a direct assessment of one or more sub-components of validity or reliability because (1) it was important to understand what evidence existed first, (2) there was not the time or resource to undertake a direct assessment in addition to the other secondary analysis work, (3) the future surveillance plans for the SHeS were unclear and so it was important to undertake work that was likely to be useful in all scenarios.

Therefore, the overall aim of the PhD programme of work was to undertake analyses on the 2012-15 SHeS datasets that would inform policy and future surveillance in Scotland. Four objectives were identified that would direct the research questions of the first four studies:

1. investigate the domain-specific contributions to total MVPA amongst adults in Scotland;
2. investigate the prevalence of MSA and BCA participation amongst adults in Scotland;
3. investigate the levels of total ST amongst adults in Scotland; and
4. review the existing evidence relating to whether the 2012-15 SHeS methods for estimating PA and ST produces valid and reliable results.

After advice from the PhD Steering Group, a decision relating to a fifth objective was delayed until the results of the first four studies were clear. My initial proposal was not deemed to be sufficiently future-proof in terms of its policy relevance. There were also concerns that other researchers may undertake similar work in the intervening period. This will be discussed in Chapter 10.

The focus was to inform national level (Scottish) policy as this was the level at which the knowledge gaps had been identified. However, this does influence local and community level policy and implementation (e.g. Highland Community Planning Partnership, 2016; The Scottish Government, 2016a). It was also an aim to take advantage of opportunities to engage with non-governmental organisations within Scotland when they arose, but these were not explicitly sought out.

5.2 How Research can Inform Policy and Surveillance

Policy-making is often described as an iterative, cyclical procedure where policy is developed, adopted, implemented, evaluated, and reformulated (Howlett & Ramesh, 1995; Nutbeam, 2004). However, the reality is that most policy-making cycles do not follow an ordered structure. Lomas (2000) argues that policy-making is not a discrete event, describing the process as ‘diffuse, haphazard, and somewhat volatile’. External factors such as the political climate and resources, or the individuals involved can play a prominent role (Bowen & Zwi, 2005; Nutbeam, 2004). In choosing the term ‘informing’ policy and surveillance, I acknowledge that my research may only be one component in decisions. Factors such as those mentioned would play an important role in the process (Nevo & Slonim-Nevo, 2011).

Figure 8 is a schematic diagram I developed to reflect how the areas of academic research, surveillance, policy, and practice interact. This has been influenced by the summary of similar models by Gentry (2017). In particular, the work of Gonzales, Handley, Ackerman, and O'Sullivan P (2012), Ogilvie, Craig, Griffin, Macintyre, and Wareham (2009), Public Health England (2015), and the experiences of C. L. Craig, Cameron, and Bauman (2016) working with national surveys in Canada, have been important. All these authors have described or created schematic overviews of the interactions between two or more of these areas. I have included practice in this model because it is important in the chain of events leading to potential behaviour change but it is not the focus of this thesis. Public health practice is hard to define but broadly it is the means through which actions are taken to improve public health (Public Health England, 2015). The three main points that Figure 8 conveys are that (1) the areas of policy and surveillance, academic research, and practice all influence each other, (2) any area can be the origin, and (3) the interactions can be an iterative process. The figure does not specifically include evaluation as it should (but in reality may not) be ubiquitous throughout the interactions, underpinning processes within a group of people or the interactions between them.

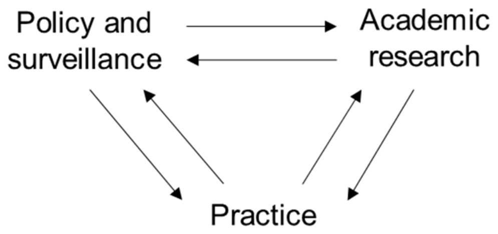

Figure 8. Schematic Overview of the Interactions Between Policy and Surveillance, Academic Research, and Practice.

A valid criticism of Figure 8 is that it still implies some logical order to the process, which, as described, can be slowed or de-railed by many unpredictable factors. Also, it does not reflect that some interactions may be harder to achieve than others, or the potential barriers to the uptake of academic research. Examples of these include mutual mistrust or resource constraints (Innvaer, Vist, Trommald, & Oxman, 2002). However, this is a better reflection of the process than a linear model (see Figure 9), that is often implied by the word 'dissemination' or 'knowledge transfer' (Ingold & Monaghan, 2016). Such a simplistic overview is unhelpful, as it can lead to the conclusion that improving the uptake of academic research by policy-makers is just about better communication (Brownson, Royer, Ewing, & McBride, 2006). This may overlook the more complex interactions described, which may require alternative solutions (Giles-Corti et al., 2015; Pratt et al., 2016).

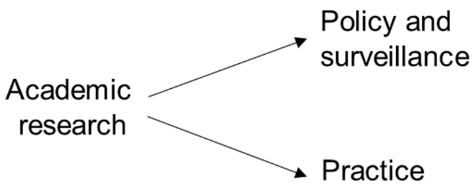

Figure 9. Linear Model of Evidence-based Policy and Practice.
Adapted from Ingold and Monaghan (2016).

5.3 Tracking Progress

Due to the complex nature of policy-making, I was aware that it would be challenging to trace any links between the work of this thesis and any changes in policy. Furthermore, it was possible that the time-scales for impact may be beyond that of this PhD. A solution to both of those issues was to use a logic model to trace any indications of research uptake and use, to provide justification for potential impacts. The 'Research Contributions Framework Pathway to Impact' model by Morton (2015) suited this purpose (Figure 10). This pathway is designed to help researchers trace the potential contributions of their research outputs and activities. I have used this model to present the evidence of uptake and use of the research in this thesis, equivalent to the arrow from academic research to policy and surveillance in Figure 8. The linear nature of Morton's model is more appropriate when one focusses on just one element of the process presented in Figure 8. However, non-linear interactions still occur when tracing the impact of academic research on policy and surveillance, and I have endeavoured to incorporate these into Morton's model.

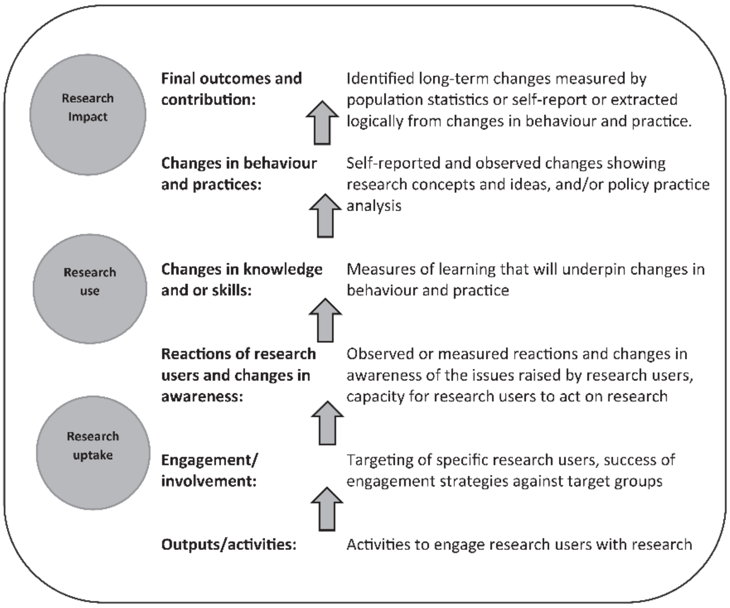

Figure 10. Pathway to Impact based on the Research Contribution Framework. From Morton (2015).

Chapter 6: Study 1 – Age-related Comparisons by Sex in the Domains of Aerobic Physical Activity for Adults in Scotland

This chapter presents work relating to Study 1: an investigation into the domain-specific contributions to the total MVPA of adults in Scotland. Study 1 was published in Preventive Medicine Reports (December 2015) and is included as part of this chapter. It is preceded and followed by additional paragraphs that expand upon the content of the paper as journal word limits did not allow for as full a discussion as is warranted in a thesis. Excessive repetition has been avoided although some is necessary to form a coherent narrative.

I led all the work, undertook all analyses, and wrote the published paper and this chapter. Dr Paul Kelly, Dr Claire Fitzsimons, and Professor Nanette Mutrie MBE assisted in the development of the methods in a supervisory capacity, and commented on drafts of Study 1 and this chapter. Professor Charlie Foster and Dr Nick Townsend were co-authors on Study 1 and a study published in 2011 using HSE data that was influential in the development of Study 1's methods. They provided assistance relating to their work, and commented on drafts of Study 1.

6.1 Knowledge Gap

Understanding the domain in which PA is undertaken is important from a public health perspective as it provides the context and setting for the behaviour. This can help direct interventions that aim to increase overall PA levels and can be used to justify or challenge current policy priorities and resource allocation.

Sport has been heavily promoted and resourced within the U.K. for many decades, potentially to the detriment of non-sporting PA such as walking or gardening (Weed, 2016). Walking has been described as the 'nearest activity to perfect exercise' (Morris & Hardman, 1997), as there are few barriers to participation. Sport, by contrast, is known to be less accessible for reasons such as cost, travel, and availability (Hulteen et al., 2017). Therefore, if a nation is concerned with overall population PA levels and minimising inequalities, it is important that its PA policy encompasses the full range of domains and that it is fully resourced.

As described in Section 4.4.3, the SHeS collects data in the domains of (1) housework, (2) gardening, heavy manual work, and do-it-yourself (DIY) maintenance, (3) sports and exercise activities, (4) walking, and (5) activity at work. Categories (1) and (2) are often condensed to ‘domestic activities’.

Prior to this study, there were only two sources of information on the domain-specific PA levels of adults in Scotland. The first was the 2011 SHeS Annual Report chapter which I wrote whilst working at ScotCen (Hill, 2012). I reported the mean hours per week spent in MVPA in each domain, by 10-year age group from age 16 to 75+ for men, women, and all adults. One criticism of the figures presented was that the mean values were heavily influenced by the individuals reporting no activity in a domain. It was not the most appropriate statistic to represent the skewed distribution of the data. This limited the insight provided on the typical domain-specific contributions to total MVPA of adults in Scotland.

The second was a Scottish Government Topic Report (secondary analyses outwith the SHeS Annual Report; Leadbetter, Geyer, & O'Connor, 2014). There were two key limitations to their analysis of the domain-specific relative contributions: (1) light intensity PA was included, and (2) total PA was pooled amongst the whole population. The latter meant it assessed how much each domain contributed to the overall PA undertaken by all adults in Scotland. This analysis method meant that the relative contributions could have been heavily influenced by those reporting high overall volumes of activity and so may not reflect the typical contributions that the domains make to the average adult in Scotland’s total PA levels. Using this method, the authors found sport and exercise activities to be the largest contributor to total PA (43% for men and 35% for women). This was without the doubling of vigorous intensity activities which, according to the SHeS analysis method, are only in the domain of sport and exercise. Walking was the second largest contributor making up 22% for men and 28% for women.

Due to the limitations with this previous research, it was still not clear what domains of MVPA adults in Scotland participated in, what the relative contributions were, and how this varied by sex, age, and between activity levels. This made challenging the domain-specific resource allocations difficult (see Section 4.3). This was a pertinent question to U.K. and Scottish PA policy at the time (2014-2015) as the evaluation of two major sporting events (2012 Olympics and 2014 Commonwealth Games) were ongoing.

6.2 Developing Previous Analyses

Bélanger, Townsend, and Foster (2011) was a key reference text when choosing the analysis method for this study. Using HSE data, Bélanger et al. (2011) investigated the relative domain-specific contributions to the total MVPA amongst adults in England who met the then MVPA 5x30 recommendation. Walking stood out as a major contributor to total MVPA across both sexes and all age-groups (between 28-45%). The authors separated sport from exercise and fitness activities (see Section 2.1 for definitions), and found a clear age-gradient for the relative contribution for both, although no differences were tested statistically. Exercise and fitness made up a greater proportion of total MVPA amongst young adults (27% and 21% for men and women aged 16-24 years, respectively) compared to those over 65 years (12% and 11%, respectively).

In consultation with the PhD Steering Group, the research question for Study 1 was finalised as: do the relative and absolute domain-specific contributions to total MVPA vary by age, for men and women living in Scotland who do and do not meet the MVPA recommendation? Table 2 displays how this analysis addresses limitations in the previous literature.

The decision to investigate the differences by age was taken because Bélanger et al. (2011) found that it was an important factor in the domain-specific contributions amongst adults in England. Age is also highly correlated with recommendation compliance amongst adults in Scotland (Hinchliffe, 2014). It is also relevant to the wider policy agenda: the CMO for England used her 2016 Annual Report to stress the need to adapt to an ageing population (Davies, 2016).

The results of Bélanger et al. (2011) also influenced the decision to stratify by sex: they indicated that there were differences between men and women that might make it inappropriate to combine analyses. It was also of policy interest to present the results separately as reducing the inequality between men and women in recommendation compliance (it is lower for women in every age group) is a stated policy aim (The Scottish Government, 2015). The extent of this inequality globally is such that if eliminated, the 2025 target (see Section 4.2) would be achieved with no change in men's MVPA levels (Mielke, da Silva, Kolbe-Alexander, & Brown, 2017).

Socio-economic position was considered as another potentially important covariate but the data available at the time suggested that the associations with MVPA recommendation compliance were not as strong as those of age and sex (Hill, 2012). The merits and limitations of this decision are discussed in Section 12.3 as it is a reoccurring theme of the thesis.

Table 2. Differences Between Study 1 and Previous Literature

Element of study method or study attribute	Bélanger et al. (2011)	Leadbetter et al. (2014)	Strain, Fitzsimons, Foster, et al. (2016)
Scottish-specific data	X	✓	✓
Pooled or individual level analyses[a]	Individual	Pooled	Individual
Analyses stratified by sex	✓	✓	✓
Analyses stratified by activity status	Active (met 5x30)	X	✓
Age group as independent variable	✓	X	✓
Absolute contributions of domains as dependent variables	X	X	✓
Relative contributions of domains as dependent variables	X	X	✓
Statistical tests performed	X	X	✓
Peer reviewed publication	✓	X	✓

Note. [a]In this context, pooled analysis refers to pooling the total minutes before deriving proportions, individual analysis refers to deriving proportions at an individual level before averaging.

6.3 Published Article

Study 1 was published by Elsevier in Preventive Medicine Reports, Volume 3, June 2016, pages 90-97 (https://doi.org/10.1016/j.pmedr.2015.12.013). Permission to publish in this thesis is granted under the Creative Commons Attribution License (CC BY 4.0; https://creativecommons.org/licenses/by/4.0/). The Supplementary File is included in Appendix 10.

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Age-related comparisons by sex in the domains of aerobic physical activity for adults in Scotland

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A R T I C L E I N F O

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Health surveys
Humans
Leisure activities
Sports
Walking

A B S T R A C T

Objective. To investigate the age-related differences in the contributions of the domains of physical activity (PA) for men and women in Scotland who met the current PA guidelines or who were insufficiently active.

Methods. We analysed data from the 2013 Scottish Health Survey (4885 adults (≥16 years)). Average weekly minutes of moderate or vigorous PA (MVPA) and the relative contributions to total MVPA were calculated for the domains of: walking, cycling, domestic, leisure, occupational, outdoor, non-team sport, team sport, and exercise & fitness. We performed linear regression analyses to assess differences by 10-year age group, stratified by sex and activity status (1–149 or ≥150 min of MVPA per week). These were repeated excluding occupational activity due to concerns with its measurement.

Results. For the 64.3% of the sample that met the guidelines, occupational activity was the most prevalent domain accounting for 18–26% of all MVPA for those under 65 years. When excluded, there was no age-related decline in total MVPA ($p > 0.05$). For the 18.6% of the sample that reported 1–149 min of MVPA per week, domestic activity was the most prevalent domain. Across both sexes and activity statuses, exercise & fitness declined with age and walking was most prevalent in the oldest age group.

Conclusion. The domains in which adults in Scotland undertake MVPA vary by age group. Policies designed to increase PA should take this into account. Our findings challenge current thinking on age-related changes in activity, with the exclusion of occupational activity mitigating any age-related decline in MVPA.

1. Introduction

Increasing physical activity (PA) levels is a successful and sustained policy priority in Scotland (The Scottish Government, 2014b). Progress is primarily monitored by the proportion of the population meeting the aerobic component of the guidelines (150 min moderate activity, or 75 min of vigorous activity or equivalent combination per week) (Department of Health, 2011), as reported annually by the Scottish Health Survey (SHeS). In 2013, 64% of the adult population in Scotland met these guidelines, an increase of 2% on the previous year. The current UK PA guidelines for adults also include statements on muscle strengthening and sedentary time, but specific indicators and policies for these modes are yet to be developed. This paper focusses solely on aerobic PA.

The SHeS records PA under the domains of domestic, occupational, sport and exercise, and walking. This information is important from a public health perspective as it provides the context in which PA is undertaken, potentially informing better intervention and policy design.

In England, Bélanger et al. (2011) found considerable age-related differences in the relative contributions of the domains of PA amongst adults who met the previous guidelines (30 min of moderate of vigorous PA (MVPA) on 5 days of the week). For example, the contribution of sports was negligible amongst older adults. Walking accounted for 26–42% of total MVPA in men and 37–45% in women and was the largest contributor for all age groups in both sexes, apart from in men aged 35–54 for whom occupational is. This highlights the need for

Abbreviations: PA, physical activity; MVPA, moderate and vigorous physical activity; SHeS, Scottish Health Survey; MET, Metabolic Equivalent of Task.

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interventions to be specific to the demographic characteristics of the target group. Whether the situation is the same in Scotland and with respect to the current PA guidelines is unknown.

This paper addresses this knowledge gap by providing Scottish-specific data on the age-related differences in the domain-specific contributions to total MVPA for men and women in Scotland. In addition, we provide a more in depth analysis than that of Bélanger et al. (2011) in four ways. Firstly, we present the absolute contributions, in addition to the relative contributions, of the domains of PA. This provides a fuller picture of where interventions are best targeted. Secondly, we performed the analyses on those who do not meet the current PA guidelines thus helping to identify potential domains to target and increase the proportion of adults meeting the PA guidelines. Thirdly, we ran our analyses both with and without the domain of occupational activity due to concerns that the measurement of this domain may distort the overall picture. Lastly, we performed statistical tests to assess whether the differences identified are statistically significant. Based on the results of Bélanger et al. (2011), we expected to see variations by age in the contributions of the domains of PA for men and women who met the guidelines. We were uncertain as to whether this would be the case for those who did not meet the guidelines.

2. Methods

2.1. Data source

We acquired the 2013 SHeS individual level dataset from the UK Data Archive (ScotCen Social Research) on 5th Feb 2015. The SHeS is designed to be nationally representative of the population living in private households in Scotland. The main survey consists of a computer aided personal interview during which PA data are collected. These are carried out over the whole year. Further information on the SHeS can be found in Corbett et al. (2014).

2.2. Questionnaire

The SHeS asks about PA in four domains in the 28 days prior to interview: (1) home-based activities (housework, gardening, building work and do-it-yourself home maintenance); (2) activity at work; (3) sports and exercise; and (4) walking. Further information can be found in the 2013 SHeS main and technical reports (Corbett et al., 2014; Hinchliffe, 2014). There have been no assessments of the questionnaire's validity or reliability to date but it is used to as the main source of data to inform Scottish PA policy. The similar but not identical Health Survey for England questionnaire demonstrated moderate convergent validity in comparison to accelerometry (Scholes et al., 2014). Average weekly time spent in these domains was converted into sub-domains developed from Bélanger et al. (2011). Activities reported under sports and exercise were allocated to leisure pursuits, outdoor pursuits, cycling, non-team sport, team sport or exercise & fitness but with cycling as independent sub-domain (see Supplementary material).

We used the same method for assigning intensity to the reported activities as used to derive the population estimates for the proportion meeting the guidelines in the SHeS annual reports. Only activities that are of at least moderate intensity count towards the PA guidelines and therefore were included in these analyses. Briefly, this excluded light housework, slow or steady average paced walks, and certain sport and exercise activities considered of light intensity such as snooker or darts were excluded. Heavy housework, brisk or fast paced walks and any occupational activity were considered of moderate intensity. Other sport and exercise activities were either categorised as moderate or vigorous in all situations, or were dependent on the answer to a follow up question that asked whether the activity makes the participant breathe faster, feel warmer or sweat to distinguish between the two intensity levels. These were based on the standardised Metabolic Equivalent of Task (MET) levels where light intensity is 1.6–2.9 METs, moderate is 3–5.9 METs and vigorous is ≥6 METs (Ainsworth et al., 2011). The duration of vigorous intensity activities was doubled to reflect the alternative ways of meeting the PA guidelines. A list of the intensity levels of the different sport and exercise activities is in the Supplementary material.

2.3. Sample

There were 4894 adult (age ≥ 16 years) responses to the 2013 SHeS. The decision to include 16–18 year olds was made to maintain comparability as they are considered adults in the UK health surveys and reported on as such, despite the adult UK PA guidelines applying to those aged 19 years upwards (Department of Health, 2011). We excluded cases if they reported implausible/incomplete values (over 10 h per day in one domain) (n = 9). If there were missing data for an individual sport or exercise activity, or for a whole domain, the contribution of this activity or domain was set to 0 rather than excluding the whole case.

The current analysis included the remaining 4885 adults. Activity status was determined by average reported weekly PA: those reporting no minutes of MVPA (n = 909), insufficiently active individuals reporting 1–149 min (n = 960) and active individuals reporting ≥150 min (n = 3016). Those reporting 0 min of MVPA were not included in any further analysis because the denominator of a percentage cannot be zero.

2.4. Statistical analyses

The relative proportions and the weekly minutes of MVPA of each domain were calculated for each individual who reported any MVPA (n = 3976). Linear regression analyses were used to assess differences in the absolute and relative contributions of the domains stratified by sex and activity status and split by age group (16–24, 25–34, 35–44, 54–64, 65+). Differences in total MVPA were also assessed. We did not run regression analyses if the maximum relative contribution of the domain was <10%.

Individuals who reported ≥150 min MVPA per week were analysed twice; (1) with occupational activity included; and (2) with occupational activity excluded (even if this took them under 150 min MVPA, although those who dropped to 0 min (n = 63) had to be excluded as the denominator could not be 0). This was because a low number of individuals reported a very high level of occupational PA, potentially distorting the findings; by conducting both analyses we could assess this effect. Only the relative contributions and total MVPA were reported and reanalysed using regression analyses as the exclusion of the 63 individuals barely altered the absolute contributions (a maximum of 6 min). No insufficiently active individuals reported any occupational activity.

All analyses were conducted in STATA/SE 14.0 using the “svyset” command to take into account the complex sampling design. This included using the weights provided by the SHeS to account for non-response bias and unequal selection probabilities to ensure reliable population estimates (Corbett et al., 2014).

3. Results

We found 64.3% of the sample (unweighted n = 3016) reported ≥150 min of weekly MVPA and therefore met the PA guidelines; 18.6% (unweighted n = 960) were insufficiently active reporting between 1 and 149.99 min of MVPA per week; 17.2% (unweighted n = 909) did not report any minutes of MVPA. As shown in Table 1, the proportion of adults meeting the PA guidelines decreased with age in both sexes. The proportion reporting 0 min of weekly MVPA increased with age in

Table 1
Percentage of adults in Scotland who report no moderate and vigorous physical activity (MVPA), insufficient MVPA or sufficient MVPA to meet the MVPA guidelines[a] in 2013, by age category and sex.

Average weekly minutes of MVPA	Men							Women						
	16–24	25–34	35–45	44–54	54–65	65+	All	16–24	25–34	35–45	44–54	54–65	65+	All
0	5.3	4.7	11.1	10.1	20.6	34.1	14.9	10.0	7.5	10.7	15.0	23.8	39.2	19.2
1–149.99 (insufficiently active)	7.2	11.6	15.2	13.6	18.5	19.0	14.4	19.7	19.2	20.4	18.8	27.0	27.3	22.4
150+ (active)	87.5	83.7	73.7	76.3	60.9	46.9	70.6	70.3	73.4	68.8	66.2	49.1	33.5	58.4
Unweighted bases	204	311	339	394	353	534	2135	241	419	431	538	442	679	2750
Weighted bases[b]	334	370	387	437	366	446	2340	332	389	411	459	383	567	2542

[a] 150 min moderate activity, or 75 min of vigorous activity or equivalent combination per week.
[b] Sample weights are applied to account for non-response bias and unequal selection probabilities.

both sexes. We assessed the concurrent validity for our domain based approach by comparing to figures reported in the Scottish Health Survey 2013 main report and found our figures were within 0.1% (Hinchliffe, 2014). The minor discrepancies were due to our exclusion of implausible and incomplete cases.

Domestic activity was the most prevalent domain for both sexes in the insufficiently active category, accounting for between a third and three quarters of total MVPA across the age groups (Fig. 1). Exercise & fitness and walking accounted for most of the remainder, although the average weekly minutes were low (Table 2). There was a significant effect of age group on the absolute and relative contributions of the three main domains with the exception of the absolute contributions of domestic activity for men (all $p < 0.05$). In the case of domestic activity, this was due to fluctuations across the age groups rather than a clear trend. For exercise and fitness, the absolute and relative contributions to total MVPA gradually declined with age for both sexes, whereas for walking, the relative contributions were highest for both sexes in the 65+ category and the absolute contributions were only matched by younger men. Total MVPA did not vary by age group.

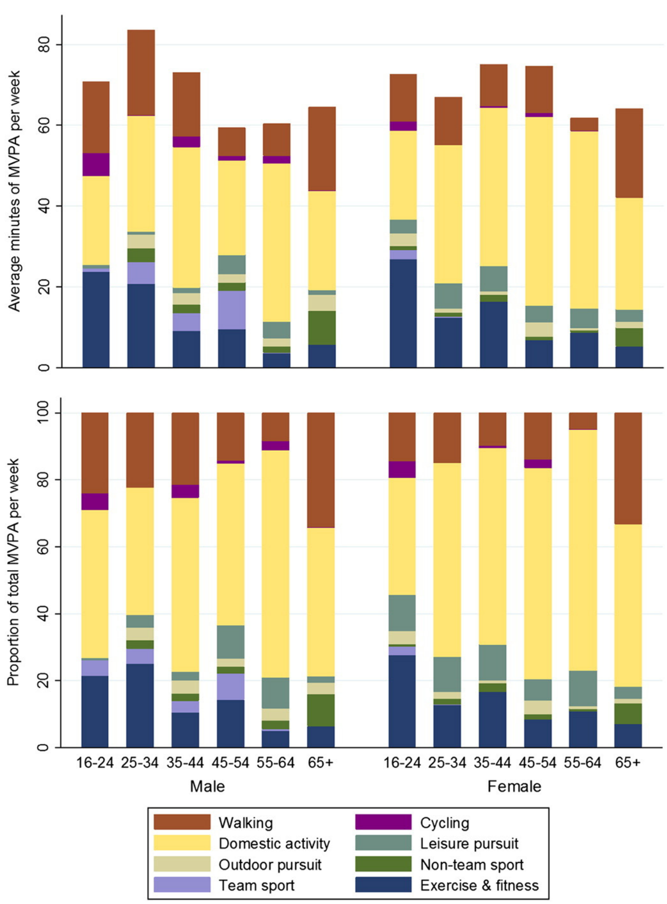

Fig. 1. Domain-specific mean weekly minutes of moderate and vigorous physical activity (MVPA) and their respective relative contributions to total MVPA of adults in Scotland not did not meet the MVPA guidelines in 2013 (n = 960), by age category and sex.

Amongst adults who met the aerobic guidelines, occupational activity was the most prevalent domain for those under the age of 65 in both sexes accounting for 18–26% of all MVPA (Fig. 2, Table 3). Total weekly MVPA decreased with age for both men and women ($p < 0.001$).

The high durations of occupational activity were due to around one quarter of those who met the guidelines (unweighted n = 741) reporting a large amount of activity in this domain (n = 414 reported over 2100 min/35 h per week). Therefore, total weekly MVPA and the relative contributions of the domains are presented excluding the domain of occupational activity (Fig. 3, Table 3). According to these data, there was no significant decline in total weekly MVPA by age ($p > 0.05$). Walking, domestic activity and exercise & fitness together accounted for around three quarters of all MVPA for both sexes. The absolute and relative contributions of these domains varied significantly by age group for both sexes, with the exception of the absolute contribution of walking in women. Exercise & fitness declined with age for both sexes whilst domestic activity increased. As with the insufficiently active, the over 65 s had highest relative contributions for walking and the absolute values were only exceeded by young women. Team and non-team sport accounted for between 5 and 20%, with the higher relative proportions amongst men in the youngest and oldest age groups.

4. Discussion

Our paper presents the first nationally representative domain-specific analysis of PA for adults in Scotland. We aimed to investigate the age-related variations in the domain-specific contributions to total MVPA by sex and activity status. We found significant variations in the most prevalent domains for men and women who met current aerobic guidelines and who were insufficiently active. We also found that, amongst those who met the guidelines, there was no evidence of a decline in total MVPA when occupational activity was excluded.

Occupational activity is challenging to assess and the method used in the SHeS inflates estimates and distorts analyses. All other domains are derived from the responses to specific questions on relevant activities. For occupational activity, individuals who report being 'very physically active at work' are allocated 40 or 20 h (for full or part time workers respectively) minus their reported sedentary time at work, of moderate activity per week, overwhelming all other domains. Those who report being 'fairly active at work' or other less active options are not allocated any occupational MVPA.

Table 2
Age-related variations in the domain-specific minutes of weekly moderate and vigorous physical activity (MVPA) and their respective relative contributions to total MVPA for adults in Scotland who did not meet the MVPA guidelines[a] in 2013, by sex.

	Men															
	16–24		25–34		35–44		45–54		55–64		65 +		All		Main effect of age	
	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution	Mean min MVPA	Relative contribution
Exercise and fitness	23.6	21.5	20.7	25.1	9.1	10.4	9.6	14.2	3.5	5.1	5.7	6.4	9.7	11.7	*	*
Team sport	1.0	4.6	5.5	4.5	4.3	3.5	9.6	7.8	0.2	0.5	0.0	0.0	3.2	3.0	–	–
Non-team sport	0.0	0.0	3.3	2.4	2.2	2.1	2.0	2.2	1.5	2.4	8.4	9.5	3.6	3.9	–	–
Outdoor pursuit	0.0	0.0	3.5	3.8	2.8	3.9	2.1	2.3	2.1	3.8	4.1	3.4	2.7	3.2	–	–
Leisure pursuit	0.8	0.8	0.6	3.8	1.4	2.6	4.7	9.9	4.0	9.2	1.1	2.0	2.3	5.1	–	–
Occupational	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
Domestic	21.9	44.2	28.7	38.0	34.8	52.1	23.4	48.4	39.2	67.8	24.5	44.4	29.4	50.3	ns	*
Cycling	5.8	4.9	0.1	0.1	2.6	3.9	1.0	1.0	1.9	2.9	0.2	0.1	1.5	1.8	–	–
Walking	17.6	24.1	21.1	22.2	15.9	21.5	7.0	14.1	8.0	8.3	20.6	34.2	14.7	21.0	*	**
Total	70.8		83.6		73.1		59.3		60.4		64.5		67.1		ns	
Unweighted bases	18		40		48		58		56		108		328			
Weighted bases[b]	24		43		59		59		68		85		338			
	Women															
Exercise and fitness	26.8	27.8	12.3	12.8	16.4	16.6	6.8	8.3	8.7	10.9	5.2	7.1	11.2	12.5	**	*
Team sport	2.3	2.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	–	–
Non-team sport	0.9	0.8	0.9	1.5	1.7	2.7	0.9	1.5	0.6	0.7	4.7	6.1	2.0	2.7	–	–
Outdoor pursuit	3.2	3.8	1.0	2.0	0.8	0.7	3.5	4.2	0.5	0.7	1.4	1.3	1.6	1.9	–	–
Leisure pursuit	3.3	10.8	6.3	10.6	6.2	10.8	4.0	6.3	4.8	10.7	3.0	3.7	4.4	8.1	ns	*
Occupational	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
Domestic	22.0	34.9	34.2	57.9	39.4	58.9	46.8	63.3	43.8	72.0	27.6	48.5	35.4	56.2	**	**
Cycling	2.4	5.1	0.0	0.1	0.4	0.5	1.0	2.5	0.1	0.3	0.0	0.0	0.5	1.1	–	–
Walking	11.5	14.3	11.8	14.9	10.2	9.9	11.5	13.9	3.2	4.7	22.1	33.3	12.7	17.1	**	**
Total	72.5		66.9		75.0		74.6		61.7		64.2		68.2		ns	
Unweighted bases	46		83		92		109		110		192		632			
Weighted bases[b]	65		75		84		86		104		155		569			

–: Regression not performed as relative contribution does not exceeded 10%.
ns: Not significant at $p < 0.05$.
[a] 150 min moderate activity, or 75 min of vigorous activity or equivalent combination per week.
[b] Sample weights are applied to account for non-response bias and unequal selection probabilities.
* Significant at $p < 0.05$.
** Significant at $p < 0.01$.

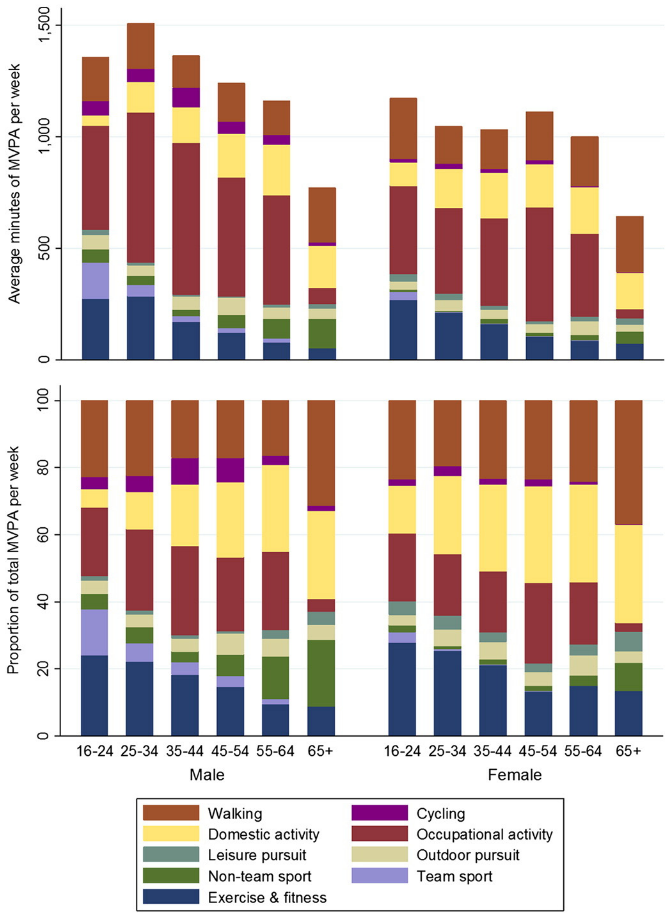

Fig. 2. Domain-specific mean weekly minutes of moderate and vigorous physical activity (MVPA) and their respective relative contributions to total MVPA of adults in Scotland who met the MVPA guidelines in 2013 (n = 3016), by age category and sex.

Removing the domain of occupational activity highlights that for adults in Scotland who meet the guidelines, MVPA does not decline with increasing age as commonly thought (Nelson et al., 2007).

This is a novel finding as previous work has focussed on the reduction in the proportion meeting the guidelines with age, with or without the domain of occupational activity (Allender et al., 2008; Berger et al., 2005). These results are compatible: those who continue to meet the guidelines maintain MVPA levels. However, as age increases, a greater proportion report insufficient or no MVPA, a finding also reported in this study. This is a more nuanced view of how PA varies with age as it implies that a significant proportion are maintaining their MVPA levels — a positive message that should not be lost.

Whilst the cross sectional nature of these data prevents in-depth analysis of the retirement transition, this paper contributes to the literature surrounding changes in PA levels and domains at this stage of life (the average age of retirement in the UK was 63 years in 2010 (Office for National Statistics, 2012)). There is currently no consensus as to how retirement alters total PA although it is clear that it is modified by occupation type (Barnett et al., 2012). These data are also consistent with increases in exercise and leisure-time activity after retirement (Barnett et al., 2012), as the absolute and relative amounts of walking and non-team sport in those over 65 were amongst the highest reported in any age group. Further investigation showed this was mainly due to higher levels of golf and bowls in the older age groups.

This analysis also challenges the assumption that more intense activities are not relevant for the older ages. These data show that both active and insufficiently active older adults take part in activities in the domains of exercise & fitness and non-team sport, although walking and domestic activity are the major contributors to total MVPA. These findings are in line with recent data from national survey of Australian adults that showed walking participation increased with age, and that although participation in aerobics/fitness training decreased with age, it was still prevalent amongst adults aged 50+ (Eime et al., 2015). Our results support the current efforts in Scotland to develop and evaluate walking interventions (Macmillan et al., 2011; Mutrie et al., 2012) but are an important reminder not to place or encourage limits on the types of activity undertaken.

Analysis of PA by two strata of activity (the active and the insufficiently active) allows novel consideration by an important grouping variable. Analysis by domain elucidates how these levels are achieved. Domestic activity is the largest contributor to total MVPA amongst the insufficiently active. This group still takes part in walking, exercise & fitness, team and non-team sports but the average total durations are insufficient to meet PA recommendations. This suggests that policy for the insufficiently active could focus on increasing the duration of current activities, rather than the uptake of new activities.

Our findings have two main differences to those of Bélanger et al. (2011). Firstly, we found that non-team sport was a much greater contributor to total MVPA, particularly amongst older adults, compared to the results of Bélanger et al. (2011). This may demonstrate real differences in the countries' participation levels of the most prevalent sports in this category (golf, bowls and tennis). Or, it may be the result of some updates to the SHeS that occurred in 2012. These included the extension of the prompts for sport and exercise activities and the realignment of the intensities assigned in accordance with the latest MET compendium (Ainsworth et al., 2011). Overall, these changes led to higher reporting of sport and exercise activities and a net increase in the activities that count as MVPA. The new guideline also meant vigorous sports 'counted double' therefore increasing their contributions to total MVPA. Secondly, we reported lower relative contributions for walking across all ages than Bélanger et al. (2011) (approximately 10–20 percentage point differences). It is not clear whether this is a result of the small increases in other categories where the duration of vigorous activities has been doubled or whether this is a true difference.

The strengths of our study are that it is novel analysis for Scotland with policy implications. It is based on a nationally representative sample, reflecting the self-reported PA habits of adults in Scotland and provides comparable results to published analysis from England (Bélanger et al., 2011). The decision to exclude extreme implausible outliers was taken to maximise the comparisons with monitoring statistics and due to the nature of the data itself. The comprehensive nature of the questionnaire and the assumptions necessary to generate summary variables, such as doubling the duration of vigorous intensity activities to account for the flexibility in the guidelines (see Corbett et al. (2014) for details) appear to result in consistently higher total MVPA than might be considered typical. Given the convergent validity of the questionnaire has not been tested against an accepted gold standard, we cannot rule out the overestimation of MVPA levels and the proportion meeting the guidelines. However, there were no differences in the conclusions when the analyses were re-run with a stricter approach to outliers (excluded all with average daily MVPA >10 h). Similarly, there were no differences to the conclusions when the analysis was re-run excluding cases with missing data on any items from the entire analysis.

We did not divide the '65+' age group further in order to maintain sample size and maintain comparability to Bélanger et al. (2011). Additionally, the current PA guidelines provide recommendations for those

Table 3
Age-related variations in the domain-specific minutes of weekly moderate and vigorous physical activity (MVPA) and their respective relative contributions to total MVPA, with and without the domain of occupational activity, for adults in Scotland who met the MVPA guidelines[a] in 2013, by sex.

	Men											
	16–24			25–34			35–44			45–54		
	Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational
Exercise and fitness	273.4	24.0	29.3	284.7	22.0	28.0	169.9	18.1	21.6	119.0	14.6	17.4
Team sport	160.3	13.8	16.2	49.1	5.7	7.6	25.9	3.8	5.8	24.1	3.2	4.1
Non-team sport	59.7	4.5	5.5	41.5	4.7	5.3	28.7	3.2	4.4	57.5	6.5	7.6
Outdoor pursuit	65.2	4.0	5.2	47.6	3.7	4.6	59.8	3.9	4.8	76.9	6.3	7.1
Leisure pursuit	22.8	1.4	2.2	14.4	1.3	2.1	8.1	0.9	1.6	5.5	0.7	1.0
Occupational	468.1	20.4	N/A	671.6	24.3	N/A	679.4	26.6	N/A	534.5	22.1	N/A
Domestic	44.3	5.5	8.6	134.9	11.0	16.7	160.9	18.3	27.7	196.0	22.3	31.8
Cycling	65.5	3.5	4.7	58.5	4.9	6.6	86.2	8.0	10.7	53.0	7.3	8.7
Walking	196.1	22.9	28.4	205.7	22.4	29.1	144.8	17.1	23.4	173.2	17.0	22.3
Total including occupational	1355.4			1507.9			1363.6			1239.6		
Total excluding occupational[b]	904.5			842.9			706.0			730.7		
Unweighted bases	176			258			255			292		
Weighted bases[c]	293			310			285			333		
	Women											
Exercise and fitness	267.5	27.8	33.8	210.5	25.4	28.6	160.0	21.2	23.4	104.4	13.2	15.8
Team sport	34.5	3.2	3.9	3.6	0.5	0.7	1.6	0.1	0.1	1.9	0.2	0.3
Non-team sport	13.7	2.0	2.3	4.7	0.8	0.8	21.0	1.5	1.6	12.8	1.4	1.6
Outdoor pursuit	36.2	3.0	4.0	50.4	5.0	5.9	40.4	5.2	5.7	39.2	4.2	4.6
Leisure pursuit	32.2	4.0	7.0	28.0	4.1	5.5	17.7	2.9	3.5	15.0	2.6	3.8
Occupational	396.0	20.3	N/A	382.8	18.3	N/A	393.3	18.1	N/A	510.6	24.1	N/A
Domestic	103.8	14.2	18.5	173.9	23.3	30.6	203.1	25.8	36.0	190.7	28.6	43.1
Cycling	16.6	1.9	2.0	23.4	2.9	3.0	17.8	1.8	2.1	19.6	2.1	2.3
Walking	271.9	23.6	28.6	169.3	19.6	24.8	177.0	23.4	27.6	218.0	23.5	28.6
Total including occupational	1172.3			1046.5			1031.9			1112.2		
Total excluding occupational[b]	788.5			669.2			649.5			616.5		
Unweighted bases	166			307			294			350		
Weighted bases[c]	223			286			283			304		

–:Regression not performed as relative contribution does not exceeded 10%.
ns: Not significant at $p < 0.05$.
[a] 150 min moderate activity, or 75 min of vigorous activity or equivalent combination per week.
[b] Totals may not add up due to the exclusion of 63 individuals who dropped to 0 min of MVPA per week once occupational was excluded. The bases shown refer to the sample sizes for the calculations including occupational activity.
[c] Sample weights are applied to account for non-response bias and unequal selection probabilities.
*Significant at $p < 0.05$.
**Significant at $p < 0.01$.

over 65 as one group and therefore this division has policy relevance. However, we acknowledge that this age group is likely to be heterogeneous in their PA behaviours and a further division at age 75 would give further insight into the population changes in the domains of activity a decade after the typical retirement age. In any case, analysis of this group individually should be approached with caution as the SHeS is only representative of the population in private houses and does not include individuals who reside in residential care homes. Therefore the sample in this age group is potentially atypical of the population as it is likely to exclude frailer individuals.

The interpretation of the results is limited by the cross sectional nature of the study. Furthermore, the sample sizes for some age groups amongst the inactive are very low, potentially limiting their ability to reflect the wider population. This analysis would be improved if active travel could have been considered as a separate domain. Despite active travel being a government priority (Transport Scotland, 2014), there is no way of determining whether the walking or cycling reported in the SHeS falls under this category and how this varies by age group.

These findings have implications for informing PA policy and promotion in Scotland. They show the need to increase PA across all domains. Walking and occupational activity were the most prevalent domains and should receive at least equal attention as sport and exercise. An important domain will be walking due to its accessibility across age and social inequality as promoted by the National Walking Strategy (The Scottish Government, 2014a). Analysis has shown walking, even at low levels, can significantly reduce risk for all-cause mortality (Kelly et al., 2014) and increase health-related fitness (Kelly et al., 2011). However, it is evident that sports and exercise are still acceptable across age and gender, even in the insufficiently active. We feel this suggests that nuanced policy could focus onto increasing engagement in existing activities, rather than policy to promote new activities.

5. Conclusions

In conclusion, this paper provides nationally representative data for Scotland on how the domains of PA vary by age for both sexes and different activity statuses. The results highlight how the measurement of occupational activity distorts our understanding of the situation, as once the domain is excluded from analyses, total MVPA did not decline across the age groups for those who continue to meet the PA guidelines.

Men											
55–64			65+			All			Main effect of age		
Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational	Mean min MVPA	Relative contribution	Relative contribution excl. occupational
77.9	9.5	11.5	52.2	8.8	9.2	172.1	16.8	20.4	**	**	**
17.0	1.5	2.1	0.8	0.1	0.1	49.3	5.0	6.4	**	**	**
87.1	12.8	13.3	129.3	19.7	20.1	63.0	7.7	8.6	**	**	**
54.2	5.4	5.7	46.9	4.7	4.7	59.5	4.7	5.4	–	–	–
10.5	2.5	3.0	20.4	3.8	3.9	13.2	1.6	2.2	–	–	–
491.6	23.3	N/A	73.4	3.8	N/A	509.3	20.8	N/A	**	**	N/A
224.9	25.8	40.0	188.5	26.2	27.6	154.6	17.5	24.7	**	**	**
43.7	2.8	3.4	12.5	1.4	1.4	55.6	4.9	6.3	**	**	**
152.2	16.5	21.0	246.6	31.5	33.0	184.9	20.8	26.0	*	**	**
1159.2			770.6			1261.6			**		
690.1			704.3			769.9			ns		
219			245			1445					
223			209			1653					
Women											
86.6	15.0	16.8	72.8	13.5	13.5	154.7	19.6	22.4	**	**	**
0.6	0.1	0.1	0.1	0.0	0.0	6.9	0.7	0.8	–	–	–
23.1	3.0	3.1	52.9	8.3	8.3	19.4	2.5	2.6	–	–	–
62.5	6.0	6.6	29.7	3.5	3.5	42.8	4.5	5.1	–	–	–
21.9	3.3	3.6	29.3	5.9	5.9	23.4	3.7	4.8	–	–	–
370.8	18.5	N/A	41.4	2.6	N/A	367.8	17.8	N/A	**	**	N/A
207.1	29.1	38.7	164.2	29.3	30.8	174.9	24.9	33.3	**	**	**
7.1	0.8	1.0	1.1	0.1	0.1	15.6	1.7	1.9	–	–	–
220.0	24.2	30.2	251.8	36.8	37.9	213.8	24.6	29.1	ns	**	**
999.7			643.2			1019.3			**		
649.5			601.8			662.3			ns		
228			226			1571					
188			190			1484					

The findings have implications for policy and practice: these data provide support for the emphasis being placed on the National Walking Strategy (CTC Scotland, 2015) and indicate that policymakers should be more sensitive to the range of domains in which PA takes place and the variations of participation across the life-course and between sexes. It is likely that the major differences between Scottish and English data are due to methodological variations but this may warrant further confirmation. The current findings should be interpreted in light of the fact that there has been no assessment of the convergent validity of the SHeS PA questionnaire against accepted gold standards; future research should address this. We are confident our analyses offer a real starting point for policy makers to examine if their interventions are promoting the right activities to the right people at the right stage of life.

Conflict of interest/funding source

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Transparency document

The Transparency document associated with this article can be found in the online version.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.pmedr.2015.12.013.

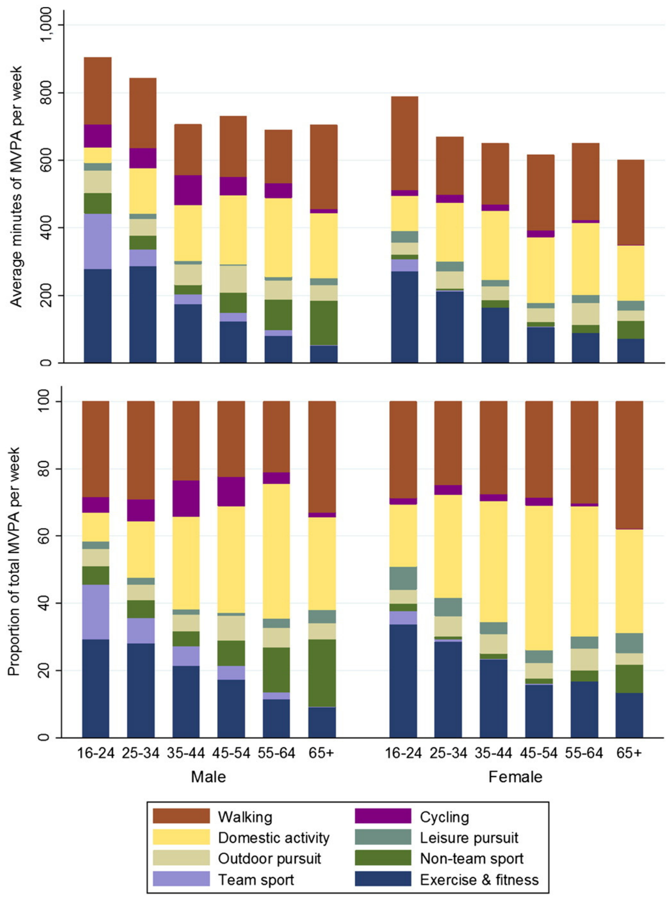

Fig. 3. Domain-specific mean weekly minutes of moderate and vigorous physical activity (MVPA) and their respective relative contributions to total MVPA of adults in Scotland who met the MVPA guidelines in 2013 (n = 3016), excluding the domain of occupational activity, by age category and sex.

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6.4 Principal Findings

The two main findings of this work were that for adults living in Scotland in 2013 (1) sport was a minority contributor to total MVPA (highest amongst men aged 16-24 and ≥65 years who met the recommendation at approximately 20%), (2) walking was a consistently important contributor to total MVPA across all age groups and sexes. The work also highlighted that the measurement of the domain of occupational MVPA may distort the interpretation of the results.

6.5 Discussion of Main Themes

6.5.1 Comparisons with other U.K. home nations

This paper made a major contribution to the growing body of literature around domain-specific MVPA using U.K. national health survey data: it developed upon the methods of Bélanger et al. (2011) and informed the methods of a further study on HSE data (Roberts, Townsend, & Foster, 2016). A paper using nationally representative data from Northern Ireland is forthcoming. These papers were the basis of a symposium at the 2016 conference for the European network for the promotion of Health-Enhancing Physical Activity (HEPA Europe). I was invited to be symposium discussant, comparing the results between the home nations. I also undertook additional analyses to illustrate the importance of considering questionnaire differences when making cross-country comparisons. Selected slides relating to this additional are included in Appendix 11, as this is an issue I refer back to in subsequent chapters.

There were four similarities between the latest data from England, the unpublished data from Northern Ireland, and the results of Study 1: (1) sport and exercise activities were not majority contributors to adults' total MVPA, (2) the contribution of the sport and exercise domains decreased with age, (3) walking was an important contributor for both sexes and all age groups, but most notably amongst those over 65 years, and (4) domestic activity was the largest contributor for the insufficiently active, but is important for the active too.

It is interesting to note that this differs from the conclusions of Leadbetter et al. (2014) who found sport and exercise activities to be the greatest contributor to the total MVPA of men and women in Scotland. Study 1 did not find this to be the case, even amongst those meeting the recommendation. It is therefore plausible to conclude that the analyses of Leadbetter et al. (2014) were heavily influenced by the high durations of sport and exercise activities reported by a minority highly active individuals. One could debate whether the ‘individual’ or ‘pooled’ analysis method (see Section 6.1) is most appropriate for determining the relative contributions of the domains. The individual method used in Study 1 represents the average contribution of a domain in the sample, where each individual counted equally[2]. The maximum an individual could contribute was 100% for a domain, regardless of the total duration. The pooled method reflects the proportion of total MVPA undertaken by the whole sample, and so more active individuals will have a greater influence over the results.

One could argue that resources are most appropriately allocated based on the latter, as it reflects the total activity undertaken. However, the dose-response relationship between MVPA and health outcomes indicates that the greatest benefits occur when an individual moves from being inactive to somewhat active, with diminishing (but important) returns on subsequent increases in activity levels (Powell, Paluch, & Blair, 2011). Therefore, if one is aiming to have maximal public health benefit, resource allocation should consider the activities of the less active.

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[2] This is correct in terms of describing the principles of the methods. In Study 1, weighting was used (see Section 4.4.2 for details) and therefore individuals technically did not count equally in the analyses.

Taken together, the three papers reiterated the key message to policy-makers: that sport is a minority contributor to the total MVPA of adults within the U.K. home nations. They also all showed walking to be a consistently prominent domain across all age groups. This put pressure on the other home nations to follow Scotland’s example of a stand-alone walking strategy to co-ordinate cross-sectoral efforts to promote the domain (The Scottish Government, 2014b). In August 2017, Public Health England responded by publishing an evidence summary to highlight the benefits of walking as a public health intervention, citing Study 1 (Public Health England, 2017).

6.5.2 Sport as an effective population-level public health intervention

The finding that walking was a greater contributor to total MVPA than team and non-team sports was supporting by findings from a systematic review including data from 47 countries (Hulteen et al., 2017). The review found walking to be the most popular PA in four out of six global regions. Along with other activities they termed ‘lifelong activities’ such as dancing, walking had much higher participation rates than team sports. Study 1 was not included in this review as it was published after the searches were conducted, although close inspection of the search terms suggests it might not have been covered by the search terms as it specified ‘U.K.’ rather than individual home nations.

The idea that some sports are not suited to ‘lifelong’ participation was also supported by data from Australian sports club memberships (Eime, Harvey, Charity, & Payne, 2016). They found considerable decreases in membership rates with age. There was also a disparity between men and women in young adulthood, a pattern also evident in the results of Study 1. This suggests that Scotland is not unique in its

PA profile and that other nations should also consider whether their strategies and resource allocations are appropriate for the activities undertaken by their population.

This discussion should not be misinterpreted as querying the effectiveness of sports on improving health outcomes (see studies such as Oja et al., 2015). Rather it questions whether sport is an effective population-level public health intervention. Weed (2016) has addressed this question directly using survey data from England to show that the decades of U.K. Government focus on sport promotion have not had the intended participation effect. The reasons for this may be explained by the findings of the Study 1 and Roberts et al. (2016): sport is a minority contributor to the total MVPA for the majority of the population.

6.5.3 Occupational and domestic activity

These findings invite the question as to whether promotion efforts should be focussed on occupational and domestic MVPA given their sizeable contribution to total MVPA. Indeed, this was asked by Scottish Government analysts at an invited presentation I gave (see Appendix 1 for details). For active individuals, these domains make up approximately 40% of total MVPA. For insufficiently active individuals, domestic activity makes up approximately 35% of total MVPA. Neither of these domains are natural targets for intervention as they are often considered compulsory activities and not necessarily within an individual's control.

Furthermore, the health benefits of both domains have been questioned. Domestic MVPA has been negatively associated with leanness (Murphy, Donnelly, Breslin, Shibli, & Nevill, 2013). The authors speculated over whether this counter-intuitive finding was because leanness affected how one self-reported the intensity of domestic activities i.e. less lean individuals may have reported activities that are not likely to alter body composition as MVPA. However, gardening (included under domestic activity) has been shown to be associated with improved mental well-being and lower body mass index (Soga, Gaston, & Yamaura, 2017).

Recent evidence has suggested that people who report being physically active at work have a higher risk of CVD, musculoskeletal problems, and mental ill-health compared to those reporting less active occupations (Holtermann, Krause, van der Beek, & Straker, 2017; Straker, Mathiassen, & Holtermann, 2017; White et al., 2017). These relationships persist after adjustment for potential confounders such as socio-economic position. Even those in occupations that require prolonged periods of standing at work have been shown to have a two-fold higher risk of CVD than those who predominantly sit (P. Smith, Ma, Glazier, Gilbert-Ouimet, & Mustard, 2017). This is an interesting new development as much of the original evidence supporting a link between PA and health came from comparisons between those in active and sedentary jobs (e.g. Morris et al., 1953b; Paffenbarger et al., 1986).

There are a number of plausible hypotheses. Holtermann et al. (2017) suggest that some manual work may induce fatigue without the health benefits if it is repetitive yet low intensity. This may plausibly affect leisure-time MVPA levels. It is also possible that confounding factors such as socio-economic position or other health-related behaviours are too closely related to job type and so statistical adjustment is not sufficient to eliminate their effects. It is also that occupational PA is too broad a category to reflect the different types and volumes of activity undertaken.

The uncertainties around the health effects of activities in these domains strengthens the case for focussing on promoting walking. The health benefits of walking have been regularly proven including improved cardio-respiratory fitness, blood pressure, and adiposity (Murtagh et al., 2015).

6.5.4 Retirement transition

Study 1 provided a new perspective on how MVPA levels might change across the retirement transition in Scotland. Whilst there are limitations of the study in relation to this topic (e.g. cross-sectional data and questions over the method of deriving occupational MVPA), the results support other literature that describes a nuanced picture of how total MVPA varies around retirement. A number of studies have found that retirement is a transitional period where MVPA levels may increase, at least in the short term (Barnett, van Sluijs, & Ogilvie, 2012; Ding, Grunseit, et al., 2016; Stenholm et al., 2016). More detailed analyses have shown that socio-economic factors strongly influence this potential change (Barnett, van Sluijs, Ogilvie, & Wareham, 2014; Barnett et al., 2012; van Dyck, Cardon, & De Bourdeaudhuij, 2016). Those who obtain a large amount of their MVPA at or travelling to or from work may not sufficiently compensate in their leisure time after retirement (Barnett et al., 2014) but that those who were not reliant on occupational MVPA to meet the guidelines may even increase their overall MVPA, at least in the early stages post-retirement (Barnett et al., 2012). Although cross-sectional, Study 1's results are consistent with these findings as, when occupational activity was excluded, the total weekly minutes of MVPA amongst those who met the MVPA guidelines did not differ between the middle and older age groups. This implies that some retirees are matching the activity levels of younger adults.

Study 1's results suggest that non-team sport is a key domain for recent retirees, particularly amongst men. Further investigation found that bowls and golf drive this trend in Scotland (see Appendix 11). Future work could focus on the retirement transition to understand how best to address the differing trajectories, that appear to differ by some measures of socio-economic status.

6.5.5 Insufficiently active

Study 1's results also suggest that many insufficiently active adults still participate in all the domains of MVPA but at an insufficient frequency or duration. For these individuals, there may be no need to take up a new activity. This is important because increasing the duration or frequency of an existing activity may be easier for many than starting a new one, as many barriers have already been overcome. The main theories of behaviour change offer tentative support for this hypothesis, as they highlight the complexity of initiating a new behaviour. For example, the trans-theoretical model identifies a number of stages that individuals need to go through before initiating a new behaviour, each with their own barriers to progression (Marcus & Simkin, 1994). Meanwhile, the 'COM-B' model that underpins the Behaviour Change Wheel suggests that individuals need to have the capability, motivation, and opportunity to perform a behaviour before change can occur (Michie, van Stralen, & West, 2011). However, those who did not report any MVPA should not be forgotten as they may require help in overcoming the barriers that prevent them from participating in any domain.

6.6 Implications for Policy

Figure 11 shows how Study 1 has contributed to Scottish policy and how it may continue to do so (for further details see Appendix 12). The issues relevant to surveillance (particularly concerning the measurement of occupational MVPA) were addressed in Study 4 and so are described in greater detail in Chapter 9.

Figure 11 is a schematic overview based on a contributions approach (Morton, 2015; see Section 5.3). It uses the framework by Morton (2015) to provide justification for the potential contribution Study 1 may have had and may continue to have on PA policy in Scotland and MVPA levels in the population. It is not able to fully reflect the multitude of other potential contributors, or their relative contributions. However, I have addressed key issues in the following paragraphs. Figure 11 does convey some of the complexity of the interactions that occurred between academic researchers, policy-makers, and other stakeholders. This experience is in accordance with the literature presented in Section 5.2 that described policy-making as a non-linear process, prone to influence from unpredictable sources (Bowen & Zwi, 2005; Lomas, 2000; Nutbeam, 2004).

The key message was that sport was a minority contributor to the total MVPA of the majority of adults in Scotland, and that walking was an important contributor for all ages and both sexes. This was a timely message, following on from the publication of the walking strategy 'Let's get Scotland walking' (The Scottish Government, 2014b). Study 1 was important because it provided peer-reviewed statistics that could contribute to increasing awareness and understanding amongst policy-makers that PA and sport were not synonymous. These were presented to the National Steering Group Evidence Sub-group, the Minister for Public Health and Sport, and the CMO. The findings were also incorporated into consultation responses, and cited in an evidence review relating to Outcome 2 on the ASOF (see Appendix 12 for full details).

In September 2017, the Scottish Government announced a doubling of the budget allocated to active travel budgets from £40 to £80 million (The Scottish Government, 2017a). As indicated in Figure 11, I believe that the change in awareness and understanding amongst policy-makers described above was an important precursor to this event. However, as Figure 11 also indicates, I acknowledge that there are other important factors that would have played a role. One example may be the emission cutting goals of the Scottish Government, which may be driven in part by their reliance on The Scottish Green Party to secure their

Programme for Government, and their commitment to the SDGs (United Nations, 2015). The contributions approach described by Morton (2015) emphasises that many factors will contribute to a policy change, but are unlikely to be sufficient to do so by themselves. This is an example of how important pragmatic cross-sectoral work is, something that was encouraged by the Toronto Charter (Bull et al., 2010).

It is interesting to consider why the potentially controversial message around the role sport has in MVPA promotion was accepted. It is likely that the additional knowledge exchange activities undertaken that often specifically addressed known barriers to academic research uptake helped (Innvaer et al., 2002). Examples detailed in Appendix 12 include accepting an invitation to present the study's findings to analysts in the Health and Social Care division at the Scottish Government, including lay summaries of Study 1 in responses to relevant consultations, and developing professional relationships with key policy-makers. The latter was aided by Dr Niamh O'Connor and Dr Justine Geyer who were on the PhD Steering Group.

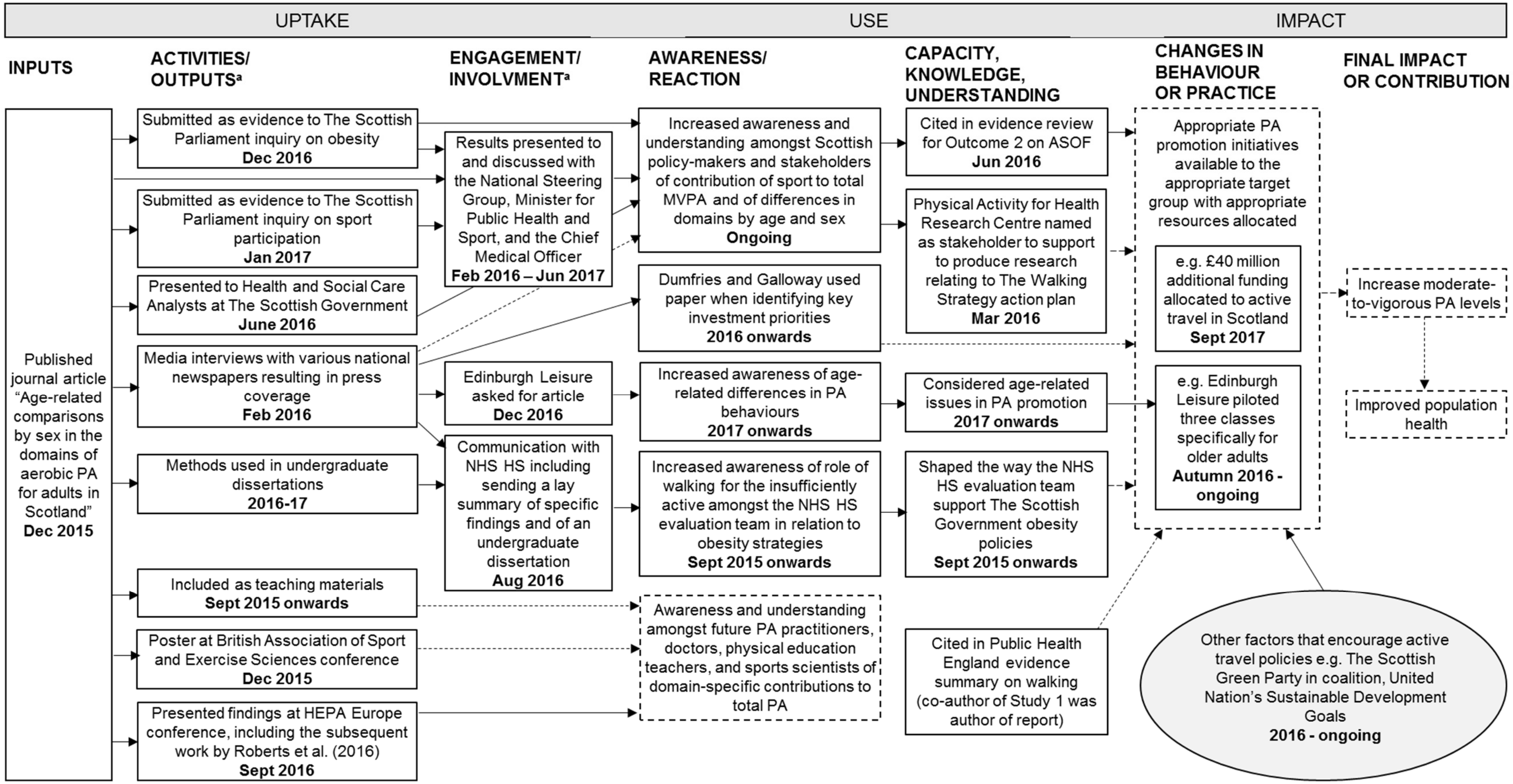

Figure 11. Tracing the Impact of Study 1.

Based on the Pathway for Impact from Morton (2015). Continuous arrows represent connections that evidence supports (see Appendix 12); dashed lines represent plausible connections. [a]Activities/Outputs covers broad knowledge exchange activities, Engagement/Involvement covers user interactions. ASOF = Active Scotland Outcomes Framework; HEPA Europe = European network for the promotion of Health-Enhancing Physical Activity; NHS HS = National Health Service Health Scotland; PA = physical activity.

6.7 Strengths and Weaknesses

Many of the strengths and weaknesses of Study 1 were discussed in the last four paragraphs of the discussion in the published article. Table 2 also summarises the ways the limitations of previous studies have been addressed in the present study. There are two additional points that are worth noting. Firstly, this chapter has focussed on aerobic activity, although it is possible that some activities included were solely MSAs or BCAs (e.g. weight training or specific balance-exercises). These are likely to be minimal and would not dramatically alter the interpretation of the results. They are more likely to be in the sport and exercise domains, and so may slightly over-estimate their relative contributions. However, these activities are also important for health and so efforts to promote them would be in line with the overall message of the 2011 U.K. CMOs' PA guidelines.

Secondly, some domains were broad. For example, walking included both travel and leisure. A recent more detailed investigation into walking behaviour suggested that while overall walking levels may be the same between men and women, there may be differences in the purpose and it may vary with age (Pollard & Wagnild, 2017). Young women walked more for leisure than young men but the gap reduced with age and even reversed in oldest age group. The lack of detail in the present study is a limitation as it could be useful in informing policy and resources appropriately.

Undertaking this work was a steep learning curve, and there were a number of points that I would have approached differently in hindsight. I made sure that these experiences informed subsequent work in this thesis. Firstly, policy-makers were interested in statistical comparisons between the sexes; this was not possible due to stratification on this variable. I had stratified on sex for two reasons (1) I made a judgement that the statistical output in Study 1 appropriately balanced insight with ease of comprehension (the *p* value presented was associated with an overall F-test that tested the null hypothesis that there were no differences by age-group in the contribution of the domain, or in total MVPA), and (2) it was most appropriate for my ability at the time as I was learning how to adapt the analyses to account for the complex sampling design. An example of the latter was that STATA SE version 14.0 (StataCorp, Texas, U.S.) svyset commands did not specifically include analysis of variance models. Therefore, I had to run linear regressions and test the null hypotheses using the 'contrasts' command.

A second issue was that some of the statistical tests were likely to be underpowered due to low sample sizes in certain sub-groups. In hindsight, greater caution should have been applied to the interpretation of the results, presenting and interpreting based on CIs rather *p* values. This would have aligned with the latest advice from the American Statistical Association that advise against interpreting results solely based on *p* values (Wasserstein & Lazar, 2016). The published paper did not provide the reader with a measure of variance so that they could make their own judgements. I made sure this information was included in subsequent publications.

Lastly, Roberts et al. (2016) updated the previous analysis of English data influenced by the methods in the present study. They simplified the number of domains but introduced socio-economic covariates into the model. They also used logistic regression to test for odds ratios of meeting the MVPA guidelines between covariate groups. All of these aspects strengthened the results of the study, in terms of ease of interpretation and policy-relevance and should have been considered in the present study's design.

6.8 Chapter Summary

In conclusion, this work has made a notable contribution to the understanding of the domains of adult aerobic PA in Scotland, and has informed national policy and surveillance. It provided recent Scottish-specific data to help to challenge the idea that sport is the solution to increasing population levels of PA, and has provided support for walking-based interventions. The recent increase in the active travel budget in Scotland was an example of an attitude shift. There are plausible links from Study 1 to the change in attitude amongst key national policy-makers. The process of influencing policy was shown to reflect the experiences of others: non-linear and prone to external influences. However, taking positive action to address known barriers to academic research uptake was a likely reason why the work has been accepted and used by policy-makers.

Chapter 7: Study 2 – The Forgotten Guidelines: Cross-sectional Analysis of Participation in Muscle Strengthening and Balance and Co-ordination Activities by Adults and Older Adults in Scotland

This chapter presents work relating to Study 2: an investigation into the participation in MSA and BCA amongst adults in Scotland. Study 2 was published in BMC Public Health (October 2016) and is included as part of this chapter. As with Chapter 6, it is preceded and followed by additional paragraphs that expand upon the content of the paper with further discussion. I led all the work, undertook all analyses, and wrote the published paper and this chapter. Dr Claire Fitzsimons, Dr Paul Kelly, and Professor Nanette Mutrie MBE acted in a supervisory capacity at all stages.

7.1 The Forgotten Guidelines

As Chapter 4 described, Scottish and global PA policy in 2014 was focussed on MVPA promotion with very few mentions of MSA and BCA in policy documents (The Scottish Government, 2014a, 2014c; WHO Regional Office for Europe, 2004; WHO. 2016). This was despite their addition to both the U.K. and global PA guidelines (Department of Health, 2011; WHO, 2010). Even global academic-led initiatives such as the Country Cards (factsheets containing indicators of PA behaviour, surveillance, and research) did not include any MSA- or BCA-related indicators (Varela et al., 2017). It was for this reason that Professor Nanette Mutrie MBE coined the phrase “the forgotten guidelines”.

7.2 Muscle Strengthening Activities and Health

Since the evidence review for the 2011 U.K. CMOs’ PA guideline update (see Section 3.3), there has been further research into the associations between

MSA and a range of physiological and psychological outcomes, using different study designs (for reviews see Bauman, Merom, Bull, Buchner, & Fiatarone Singh, 2016; Westcott, 2012). This section will briefly describe the key studies as it reinforces the case for addressing MSA at a national policy level, and for undertaking Study 2.

The most notable addition to the body of evidence was the publication of several prospective cohort studies (Dankel, Loenneke, & Loprinzi, 2016b, 2017; Evenson, Wen, & Herring, 2016; Grontved et al., 2014; Kraschnewski et al., 2016; Schoenborn & Stommel, 2011; Shiroma et al., 2017; Stamatakis et al., 2017; Zhao et al., 2014). These provided a different perspective to intervention studies as they generally observed the development of health outcomes over a longer time period. This study design enables outcomes such as ACM, CVD morbidity or mortality, and type 2 diabetes incidence to be directly investigated rather than inferred from shorter-term changes in blood lipid profiles, blood pressure, or insulin sensitivity.

All but one of the studies cited above used data from the U.S. (the exception being Stamatakis et al., 2017 who combined SHeS and HSE datasets). The conclusions were relatively consistent: self-reported participation in MSA at baseline was associated with a reduced risk of mortality or morbidity over follow-up periods of up to 15 years, adjusted for other PA. Four of these studies included younger adults (<40 years; Dankel et al., 2016b; Schoenborn & Stommel, 2011; Stamatakis et al., 2017; Zhao et al., 2014), strengthening the case for considering MSA as a whole population health issue.

There are however, a few limitations with these studies. These included issues common to many prospective cohort studies such as measurements of exposures and covariates at baseline only and difficulties in accounting for underlying disease at baseline. Another factor that was common among most the studies cited above was the relatively high levels of uncertainty around the estimates. CIs of hazard ratios are determined by the number of events in a sub-group rather than the sample size, although the two are often linked. Although overall sample sizes were often high, the low prevalence of MSA participation often meant a small sub-group sample. The direction of association of MSA participation on health outcomes was often protective, further reducing the event rate. As it is the number of events that drives the confidence intervals around the estimates, this makes it difficult to make conclusions regarding effect size. For example, Dankel et al. (2016b) estimated that meeting the MSA recommendation was associated with a 23% (95% CI: 2-40%) risk reduction in ACM, adjusted for MVPA levels.

7.3 Balance and Co-ordination Activities and Health

The key review used to support the BCA recommendation was updated in 2011 (Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011), which was too late to incorporate its conclusions into the U.K. CMOs' PA guidelines published that year. A further 10 (total of 54) randomised controlled trials were included in the meta-analysis. This provided enough evidence to conclude that two hours per week were sufficient to improve balance, although the authors did point out that there was no evidence for a clear cut-off. This provided retrospective justification for the recommendation of two sessions per week. Sherrington et al. (2011) also noted the need for balance exercises to be sufficiently challenging, and recommended that MSA should be undertaken concurrently to further reduce risk of falls. This last point was supported by a Cochrane review of interventions to reduce falls risk published the following year (Gillespie et al., 2012).

7.4 Developing Previous Analyses

The only previously published figures on MSA and BCA amongst adults in Scotland had been in the 2012-14 SHeS Annual Reports (Bromley, 2013; Gill, 2015; Hinchliffe, 2014). Prevalence of recommendation compliance was published by age group (MSA only) and by sex (MSA and BCA). It was not clear why this information was not being used by policy-makers. The PhD Steering Group speculated as to whether it was 'lost' amongst the large volumes of other statistics published, or whether it was insufficiently detailed to be of use. Differences were not tested statistically, nor was participation in individual activities investigated. The PhD Steering Group supported undertaking more detailed analyses to address these knowledge gaps. Publication in a peer-reviewed journal would add credibility to the analyses and provide an opportunity to focus policy-makers attention on the issue. Table 3 summarises the way in which Study 2 addressed the various limitations of the previous research.

I decided to investigate the differences by age and sex because Study 1 had confirmed their known associations with MVPA recommendation compliance. It was therefore important to understand whether this was the case with the other recommendations. Furthermore, there were also strong evidence to suggest that MSA and BCA are of particular relevance to older women, given their susceptibility to muscle and bone mass after the menopause (ACSM et al., 2004; Montero-Fernandez & Serra-Rexach, 2013).

Table 3. Differences Between Study 2 and Previous Literature

Element of study method or study attribute	Muscle strengthening		Balance and co-ordination	
	2012-14 SHeS Annual Reports[a]	Strain, Fitzsimons, Kelly, and Mutrie (2016)	2012-14 SHeS Annual Reports[a]	Strain, Fitzsimons, Kelly, and Mutrie (2016)
Scottish-specific data	✓	✓	✓	✓
Prevalence of recommendation compliance by sex	✓	✓	X	✓
Prevalence of recommendation compliance by age-group	✓	✓	X	✓
Interaction terms (age*sex) included	X	✓	X	✓
Participation levels in specific activities, by age and sex	X	✓	X	✓ (age only)
Statistical tests performed	X	✓	X	✓
Peer reviewed publication	X	✓	X	✓

Note. [a]2012: Bromley (2013); 2013: (Hinchliffe, 2014); 2014: Gill (2015).

7.5 Published Article

Study 2 was published by Springer in BMC Public Health in October 2016, Volume 16, pages 1108-1119 (https://doi.org/10.1186/s12889-016-3774-6). Permission to publish in this thesis is granted under the Creative Commons Attribution License (CC BY 4.0; https://creativecommons.org/licenses/by/4.0/). The Supplementary Materials and Tables are included in Appendices 8 and 13 respectively.

A note on consistency of terms: the published article uses the word gender instead of sex. This was because, at the time of writing, I was influenced by other studies using the term gender (referring to the social and cultural differences between males and females; Bennie, Pedišić, van Uffelen, Gale, et al., 2016). After publication, I clarified that the SHeS variable asked about sex (the biological differences between males and females). Therefore, this term was used in all other work. No correction has been requested of the journal as it does not affect the understanding or implications of the findings. It is interesting to note that Dogra et al. (2017) highlight the need to appropriately distinguish between these terms as a future priority for SB research.

Strain et al. BMC Public Health (2016) 16:1108
DOI 10.1186/s12889-016-3774-6

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The forgotten guidelines: cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland

Tessa Strain*, Claire Fitzsimons, Paul Kelly and Nanette Mutrie

Abstract

Background: In 2011, the UK physical activity guidelines were updated to include recommendations for muscle strengthening and balance & coordination (at least two sessions of relevant activities per week). However, monitoring and policy efforts remain focussed on aerobic activity. This study aimed to assess differences by gender and age in the a) prevalence of muscle strengthening and balance & co-ordination guidelines, and b) participation in guideline-specific activities.

Methods: The sample for the muscle strengthening analyses was 10,488 adult (16–64 years) and 3857 older adult (≥65 years) 2012–2014 Scottish Health Survey respondents. The balance & co-ordination analyses used only the older adult responses. Differences by gender and (where possible) age in guideline prevalence and activity participation were assessed using logistic regression and t-tests.

Results: Thirty-one percent of men and 24 % of women met the muscle strengthening guideline, approximately half that of published figures for aerobic physical activity. Nineteen percent of older men and 12 % of older women met the balance & co-ordination guidelines. The oldest age groups were less likely to meet both guidelines compared to the youngest age groups. Differences by gender were only evident for muscle strengthening: more men met the guidelines than women in all age groups, with the largest difference amongst 16–24 year olds (55 % men compared with 40 % women). Participation in relevant activities differed by gender for both guidelines. 'Workout at gym' was the most popular activity to improve muscle strength for men (18 % participated), while swimming was for women (15 % participated). Golf was the most popular activity to improve balance & co-ordination for older men (11 % participated) and aerobics was for older women (6 % participated). Participation decreased in most muscle strengthening activities for both men and women. One exception was golf, where participation levels were as high amongst older men as in younger age groups, although overall levels were low (3 % of all men).

Conclusions: Physical activity policy should aim to increase prevalence of these 'forgotten' guidelines, particularly amongst young women (for muscle strengthening) and older age groups (both guidelines). Gender and age participation differences should be considered when designing population-level interventions.

Keywords: Physical activity, Public health surveillance, Muscle strengthening, Balance, Co-ordination, Guidelines

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Background

Increasing physical activity (PA) levels is a health priority in Scotland [1]. Progress is monitored by the proportion of the population undertaking the recommended amount of moderate and vigorous aerobic PA [2]. Until recently, the Scottish PA guidelines for adults focused only on aerobic activity. In 2011, the guidelines were updated to include recommendations on muscle strengthening (MS), balance & co-ordination (BC; for older adults (≥65 years) at risk of falls), and sedentary behaviour [3]. This paper focuses on MS and BC. The relevant additional recommendations are:

- Those over the age of 19 should undertake two sessions of MS activities per week, and
- Those over the age of 65 who are at risk of falls should undertake two sessions of BC activities per week [3].
  (see Table 1 for a list of the activities that were considered to improve MS and/or BC).

The inclusion of the MS guidelines for adults was in response to the growing evidence base showing that higher levels of muscle strength are associated with a reduced risk of premature mortality and cardiovascular disease across all ages, independent of aerobic PA levels [4–6]. There are also metabolic benefits to undertaking regular MS activities, such as improved insulin action, blood glucose control, and fat oxidation, all of which are critical in the prevention and treatment of type 2 diabetes and metabolic syndrome [7, 8]. There is tentative evidence to suggest MS activities improve self-esteem [9], and ameliorate symptoms of depression and anxiety [10, 11].

In older adults, MS activities limit the age-related decline in lean muscle mass (sarcopenia), help prevent osteoporosis, maintain functional capacity and reduce risk of falls [12–15]. Older adults may further reduce their risk of falls by undertaking BC activities [16, 17]. Studies in New Zealand and USA have found that around one-third of community-dwelling older adults fall each year [18, 19]. Considering the health and economic burden related to falls is high [14], this issue needs to be addressed.

In response to the additional guidelines, the Scottish national surveillance questionnaire (the Scottish Health Survey (SHeS)) was expanded so the MS activities of adults and older adults, and the BC activities of older adults could be monitored annually [20]. Whilst the SHeS records aerobic PA under the domains of walking, housework, heavy manual/Do-it-yourself home maintenance/gardening, occupational, and sport and exercise, designated MS and BC activities only appear within the sport and exercise domain [20] (full list in Table 1). Therefore, we use the terms MS and BC sport and exercise activities in this paper.

So far, the SHeS annual reports have only published descriptive statistics on the proportion of adults and older adults meeting the MS guidelines (27 % in 2012 [20]). There has been no statistical examination of the differences by age and gender, nor any analysis as to what MS sport and exercise activities adults and older adults undertake. There has been no analysis relating to the BC guidelines. This paper addresses these omissions by assessing whether there are any important and statistically significant differences by gender and (where possible given available bases) age group in:

i) the MS and BC guideline prevalence (and the proportions that undertaking no or insufficient activities)
ii) the participation levels in specific MS and BC sport and exercise activities.

This will provide a baseline from which progress can be monitored, suggest which activities are important in different sub-groups, and highlight sub-groups most in need of policy focus and intervention.

Methods

Data source

We obtained the 2012-2013-2014 SHeS combined dataset from the UK data archive on 17th December 2015 [21]. The SHeS uses a two-stage stratified clustered sampling design to select households for participation in an interviewer-led computer assisted interview. After weighting, the data are nationally representative of the population living in private households in Scotland in 2012, 2013, and 2014. Further details on the sampling design and survey methods are in the SHeS Technical Report [22].

Measurement of muscle strengthening and balance & co-ordination activities in the Scottish Health Survey

Adult respondents to the SHeS were asked to report the frequency (in the 28 days prior to interview) and average duration of any sport and exercise activities that they undertook. Over 40 sport and exercise activities were prompted and they were given the opportunity to report any others (for further details see Corbett et al. (2013) [23]). A panel of experts was convened to determine whether the prompted sport and exercise activities could count towards the MS and/or the BC guidelines [20]. Table 1 displays the three categories that they were allocated to: a) definitely a MS/BC sport and exercise activity, b) only a MS/BC sport and exercise activity if the respondent confirms in a follow up question, c) not a MS/BC sport and exercise activity. The follow up question

Table 1 Activities that are considered by the Scottish Health Survey to improve muscle strength and/or balance & co-ordination

Activity*	Muscle strengthening category	Balance & co-ordination category
Aerobics/Keep Fit/Gymanastics/Dance for fitness	b	a
Aquarobics/Aquafit/Exercise class in water	b	a
Athletics	a	a
Badminton/Tennis	b	a
Basketball	b	a
Canoeing/Kayaking	a	a
Climbing	a	a
Cricket	b	a
Curling	b	a
Cycling	b	a
Dancing (any other type)	b	a
Exercises	b	b
Fishing/angling	c	c
Football/Rugby	b	a
Golf	b	a
Hill walking/Rambling	b	a
Hockey	b	a
Horse riding	a	a
Ice skating	b	a
Powerboating/Jet skiing	c	a
Lawn Bowls	b	a
Martial arts/Tai Chi	b	a
Netball	b	a
Rowing	a	c
Running/Jogging	b	c
Sailing/Windsurfing	a	a
Shinty	b	a
Skateboarding/inline skating	c	c
Skiing/Snowboarding	a	a
Snooker/Billiards/Pool	c	c
Squash	b	a
Subaqua	c	c
Surf/Body boarding	b	a
Swimming	a	c
Table tennis	c	a
Tenpin bowling	b	a
Volleyball	b	a
Waterskiing	a	a
Workout at gym/Weight Training/Exercise bike	b	a
Yoga/Pilates	b	a

*The activities are listed as they are prompted in the Scottish Health Survey. No further details are available as to exactly what the respondent was referring to when they reported undertaking this activity
a) definitely a muscle strengthening and/or balance & co-ordination sport and exercise activity
b) only a muscle strengthening and/or balance & co-ordination sport and exercise activity if the respondent confirms in a follow up question (see text for more details)
c) not a muscle strengthening and/or balance & co-ordination sport and exercise activity

for MS activities was "During the past four weeks, was the effort of (name of activity) usually enough to make your muscles feel some tension, shake or feel warm?" There was only one BC activity to require a follow-up question (exercises). The follow-up question to this activity was "Did these exercises involve you standing up and moving about?" The construct validity of this method has not been tested but we are unaware of any other validated method of assessing prevalence meeting national MS or the BC guidelines.

A respondent was deemed to have met the MS or the BC guidelines if they reported undertaking an average of ≥2 sessions of MS or BC sport and exercise activities respectively per week in the preceding 28 days. This is based on the assumption that the sessions took place on separate days. The UK PA guidelines do not specify a recommended bout length for MS or BC activities [3] and so the reported duration of activity was not taken into account. We calculated the proportions (1) achieving or exceeding these guidelines, (2) participating in some MS or BC sport and exercise activities but not sufficiently to meet the guidelines, or (3) not participating in any MS or BC sport and exercise activities.

Finally, we calculated the proportions that reported participating in each individual MS and BC sport and exercise activity in 28 days prior to interview. For category (b) activities where a follow up question was required to confirm that the activity was relevant, respondents only counted as participants if the answer was affirmative.

Sample characteristics

There were 10,509 adult (16–64 years) and 3857 older adult (≥65 years) respondents to the 2012, 2013 and 2014 SHeSs. These were analysed together for the MS analyses. Those aged 16–18 were included in the analysis in line with UK health survey reporting although the PA guidelines defines adults as 19–64 years [3]. Only older adults were included in the BC analyses as the guideline only applies to this age group. It was not possible to identify those at risk of falls (the exact target group for the recommendation) and so we have analysed the data for all those over the age of 65.

Ten respondents were excluded from the MS analyses and one from the BC analyses as they did not answer the PA questions relating to sport and exercise. If there were missing data for a specific MS or BC sport and exercise activity, the respondent was kept in the overall analysis but that activity did not count towards the weekly total. Twelve further respondents were excluded from the MS analysis and one from the BC analysis as they averaged over 3 sessions per day for the previous 28 days. We considered these individuals as extreme outliers and not representative of normal populations. The MS analyses by age group used 10-year groups in line with standard health survey reporting; 5-year age groups were used for the BC analyses to provide further insight in the already restricted age range. Table 2 shows the unweighted and weighted sample sizes for the age and gender sub-groups (Table 2).

Statistical analyses

Analyses were carried out using STATA/SE v14.1 using the 'svyset' commands to account for the design effects of the complex sampling strategy, following the recommendations of Heeringa et al. (2010) [24].

Multiple logistic regressions were performed on the proportions undertaking no, some, or sufficient MS or BC sport and exercise activities with the predictors age group, gender, and an interaction term. Significant differences compared to the reference category (youngest age group and males for the predictors respectively) were identified through Wald tests for the regression coefficients.

T-tests were performed to assess gender differences in the proportions taking part in the MS and BC sport and exercise activities (if the overall proportion participating was ≥1 %) using the 'lincom' command. Simple logistic regressions were used to test the differences in the proportions taking part in MS sport and exercise activities by age group, stratified by gender. Regressions were only undertaken if the activity featured in the top five for any age category for that gender. This was not possible for the BC sport and exercise activities as the sample sizes were too small.

A conservative Bonferroni adjusted α-level of 0.0003 was used to account for the large number of comparisons being made (184 test statistics). However, our conclusions have taken into account overall trends in the interpretation of the data and we comment only where differences appear to be of practical importance. One should be cautious interpreting these data based solely on this cut-off for statistical significance and therefore have provided the exact *p*-values and 95 % confidence

Table 2 The unweighted and weighted sample sizes for the age and gender sub-groups in the muscle strengthening and balance & co-ordination analyses

Muscle strengthening analyses								
	Age group							
	16–24	25–34	35–44	45–54	55–64	65–74	75+	Total
Men								
Unweighted	573	785	990	1165	1075	1063	669	6320
Weighted	970	1097	1101	1286	1071	812	535	6873
Women								
Unweighted	701	1082	1326	1469	1322	1180	945	8025
Weighted	966	1153	1169	1359	1125	908	780	7459

Balance & co-ordination analyses						
	Age group					
	65–69	70–74	75–79	80–84	85+	Total
Men						
Unweighted	618	445	325	207	137	1732
Weighted	487.3	325.2	260.1	160.2	114.6	1347
Women						
Unweighted	679	500	437	301	207	2124
Weighted	522.9	384.5	361.3	245	173.4	1687

Note rows may not add up due to rounding intervals for the regression analyses in the Additional Tables (see Additional file 1).

Results

Muscle strength

The proportions of men and women in Scotland in 2012–14 meeting the MS guidelines were 31 and 24 % respectively (Fig. 1, Additional file 1: Table S1). The proportions were highest amongst the youngest age group 16–24 year olds (57 % of males and 38 % of females); all other age groups were significantly less likely to meet the guidelines. The proportions decreased with age with the lowest amongst the over 75 s (9 % of men and 4 % of women in this age group). Men were more likely to meet the guidelines than women across all age groups, with the exception 35–44 year olds where the statistically significant interaction effect implied the 2 percentage point difference between the genders is with the range of variance.

The proportion doing some MS sport and exercise activities but at an insufficient frequency (>0 but <2 sessions per week over previous 28 days) to meet the guidelines ranged between 17 and 28 % for both genders between the ages of 16 and 54 years, before declining to 7 % for men and 5 % for women over 75 years. The difference between the youngest and oldest age groups was significant. Men were more likely to undertake some MS sport and exercise activities than women in the youngest age group (17 % for men and 28 % for women aged 16–24 years). Although the only interaction effect to meet our conservative α-level was for 55–64 year olds (implying no effect of gender in this age group), the difference between the genders was a maximum of two percentage points in all other (non-reference category) age groups.

The proportion undertaking no MS sport and exercise activities per week increased with age from 26 % of men and 34 % of women aged 16–24 to 84 % of men and 91 % of women over 75 years. This was significantly higher for those over the age of 35 compared with the youngest age group. There were no significant effects of gender, or interaction between gender and age group.

Figure 2 shows the participation levels (at least 1 session in the previous 28 days) by gender for individual MS sport and exercise activities that had an overall prevalence ≥1 %. Men were more likely to participate in

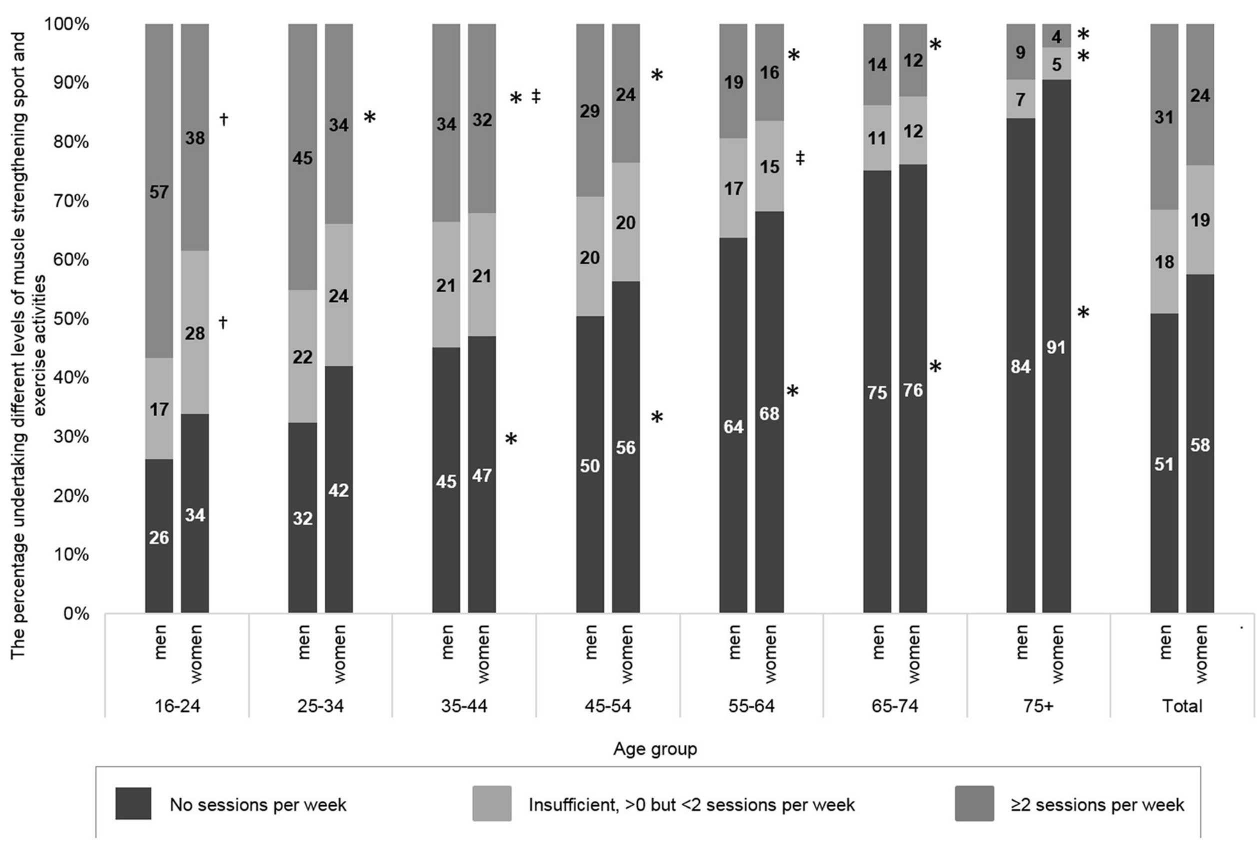

Fig. 1 Levels of muscle strengthening sport and exercise activities, by age group and gender. Weighted $n = 6873$ men, $n = 7459$ women. *significantly different from 16 to 24 year age group at $p < 0.0003$. †significantly different between genders at $p < 0.0003$. ‡significant interaction between gender and age group at $p < 0.0003$

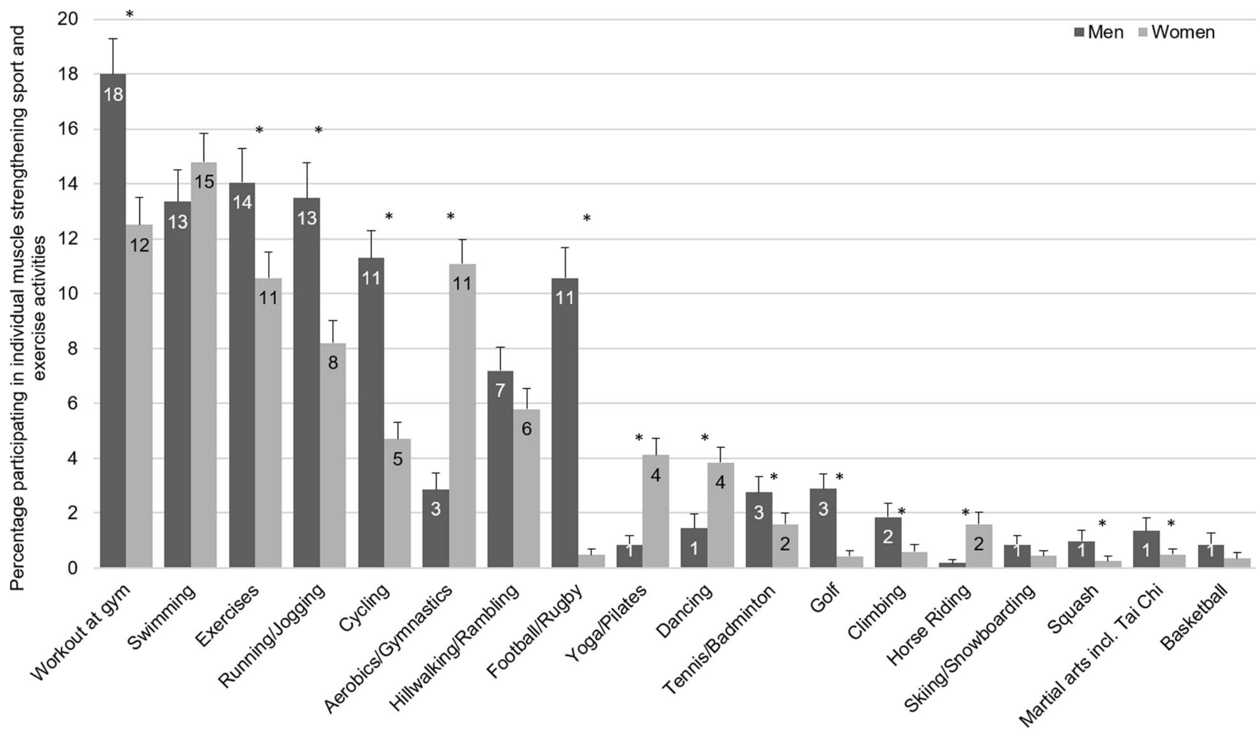

Fig. 2 Participation in muscle strengthening sport and exercise activities, by gender. Weighted $n = 6873$ men, $n = 7459$ women. *significantly different between genders at $p < 0.0003$. Workout at gym includes 'weight training' and 'exercise bike'. Aerobics/Gymnastics includes 'keep fit' and 'dance for fitness'

'workout at gym' (including weight training and exercise bike), exercises, running/jogging, cycling, football/rugby, tennis/badminton, golf, climbing, squash, and martial arts (including tai chi); women were more likely to participate in aerobics/gymnastics, yoga/pilates, dancing, and horse-riding. The difference between the genders in participation levels was not significant for swimming, hill walking/rambling, skiing/snowboarding, and basketball.

Table 3 shows the proportion participating in the top five MS sport and exercise activities in each age group, stratified by gender (see also Additional file 1: Table S2). The proportions of both genders taking part in 'workout at gym' (including weight training and exercise bike), exercises, and running/jogging were significantly lower after the age of 35 compared to those aged 16–24. The decline was later in swimming for both genders; participation levels were significantly lower for men over 65 years and women over 55 years. Hill walking/rambling participation was maintained for both men and women up until the 65–74 age group. It decreased for both sexes amongst those over 75 years, although technically not significant for men at the conservative Bonferroni-adjusted α-level. Golf participation levels increased in the middle age groups for men, and there were similar participation levels amongst the youngest and oldest age groups. However, note that overall participation levels were low (3 % of all men, Fig. 2). Football and cycling participation levels were lower for men after the age of 25 and 55 respectively, compared to 16–24 year olds. Dancing participation declined for women after 35 years, whilst aerobics participation was significantly lower for women after the age of 55.

Balance & co-ordination

The proportion of older adults meeting the BC guidelines in Scotland in 2012–14 was 19 % and 12 % for men and women respectively (Fig. 3, Additional file 1: Table S3). The proportion decreased steadily with age, from 25 % of men and 18 % of women aged 65–69 to 8 % of men and 2 % of women aged over 85 years, although the only significant difference was between the youngest and oldest age groups. There was no overall effect of gender nor any interaction effects.

The proportion undertaking some BC sport and exercise activities but at an insufficient frequency did not vary by age group or gender, ranging between 3 and 16 %. The proportion doing no BC sport and exercise activities increased with age from 60 % of men and 65 % of women aged 65–69 to 89 % of men and 94 % of women aged over 85 years. The proportions were significantly higher for those over the age of 80 compared to

Table 3 Participation in the top five muscle strengthening activities, by age group, stratified by gender

Men													
16–24		25–34		35–44		45–54		55–64		65–74		75+	
Workout at gym	36	Workout at gym	29	Swimming	18	Workout at gym	16[*]	Swimming	10	Swimming	7[*]	Swimming	4[*]
Running	32	Running	25	Workout at gym	18[*]	Swimming	15	Workout at gym	9[*]	Workout at gym	6[*]	Workout at gym	3[*]
Football/ Rugby	31	Exercises	24	Cycling	16	Cycling	15	Hillwalking	8	Hillwalking	5	Exercises	3[*]
Exercises	31	Swimming	19	Running	15[*]	Running	11[*]	Cycling	7[*]	Exercises	4[*]	Golf	3
Cycling	15	Football/Rugby	18[*]	Exercises	14[*]	Hillwalking	10	Exercises	7[*]	Golf	4[†]	Hillwalking	2
Women													
16–24		25–34		35–44		45–54		55–64		65–74		75+	
Workout at gym	24	Swimming	22	Swimming	20	Swimming	14	Swimming	12[*]	Swimming	8[*]	Aerobics	4[*]
Exercises	24	Workout at gym	20	Workout at gym	17[*]	Workout at gym	12[*]	Aerobics	7[*]	Aerobics	6[*]	Swimming	2[*]
Swimming	21	Aerobics	17	Aerobics	16	Aerobics	11	Workout at gym	6[*]	Workout at gym	4[*]	Exercises	1[*]
Running	18	Exercises	17	Exercises	14[*]	Exercises	8[*]	Hillwalking	6	Hillwalking	4	Dancing	1[*]
Aerobics	14	Running	16	Running	12[*]	Hillwalking	8	Exercises	4[*]	Exercises	3[*]	Hillwalking	1[*]

Weighted $n = 6873$ men, $n = 7459$ women
[*]significantly lower participation than 16–24 year age group at $p < 0.0003$
[†]significantly higher participation than 16–24 year age group at $p < 0.0003$. Workout at gym includes weight training and exercise bike. Aerobics includes 'keep fit', gymnastics and 'dance for fitness'

the youngest age group. There was no effect of gender or any interaction between gender and age group.

Figure 4 shows that the participation levels for older adults were low across all BC sport and exercise activities. Golf was the most popular BC sport and exercise activity for men but it had the greatest difference between the genders (11 % of older men versus 2 % of older women). Aerobics/Gymnastics (including 'keep fit' and 'dance for fitness') was the most popular activity for older women with only 6 % taking part.

Discussion

Summary of findings

This is the first paper to provide detailed nationally representative information on the proportions meeting MS and BC guidelines amongst adults and older adults, by age and gender. We found that the oldest age groups were less likely to meet either guidelines compared to the youngest age groups. However, significant differences by gender were only evident for MS (more men met the guidelines than women across all age groups). Participation in individual MC or BC sport and exercise activities varied by gender and age group.

Muscle strengthening

Approximately half as many adults and older adults in Scotland meet the MS guidelines (31 % of men and 24 % of women) compared to the aerobic PA guidelines (71 % men and 58 % of women [25]) in 2013. This calls into question whether the current focus on aerobic PA is appropriate particularly given the strong evidence demonstrating the health benefits of MS activities [4–6].

Few countries report nationally representative estimates for the proportion meeting the MS guidelines. Even amongst those that do measure relevant activities at a population level, there are large variations in the definitions and surveillance methods used, which may be obscuring or amplifying real differences. This is important to highlight given the number of inter-country PA comparisons that take place (e.g. GoPA! Country Cards [26], Active Healthy Kids Country Cards [27], the Global Burden of Disease studies [28]).

Within the UK there is a degree of consensus with both England and Northern Ireland using comparable methods to the SHeS [29, 30]. The proportions meeting the MS guidelines reported in this study are similar to those reported for England in 2012 (34 % of men and 24 % of women) [29] but are higher than Northern Ireland in 2013/14 (25 % of men and 14 % of women) [30]. In the USA, participants of the National Health Interview Survey are asked how often they do leisure-time physical activities specifically designed to strengthen their muscles such as lifting weights or doing calisthenics [31]. The 2014 survey estimated that 28 % of men and 20 % of

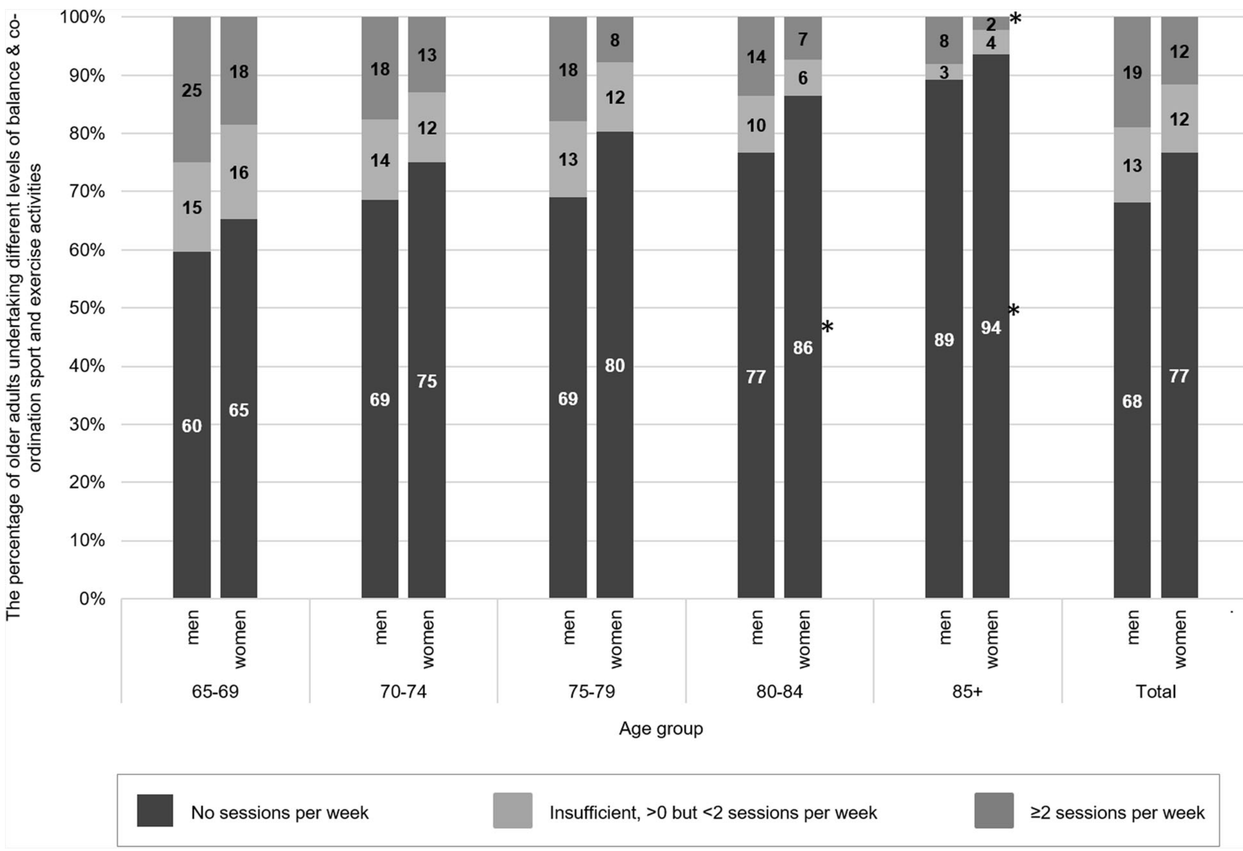

Fig. 3 Levels of balance & co-ordination sport and exercise activities, by age group and gender. Weighted $n = 1347$ men, $n = 1687$ women. *significantly different from 16 to 24 year age group at $p < 0.0003$. †significantly different between genders at $p < 0.0003$. ‡significant interaction between gender and age group at $p < 0.0003$

women in the USA undertook a sufficient quantity of MS activities to meet the guidelines [32]. In Australia, different surveys use different methods and the estimates for the proportion of adults meeting the MS guidelines range between 9 and 19 % [33, 34].

Our findings highlight three key groups for policy focus and intervention. Firstly, promotion efforts should be focussed on women, particularly in the youngest age groups. We found the largest percentage point difference between the sexes was amongst 16–24 year olds (57 % compared with 38 %). This is concerning as bone and muscle mass peak in early adulthood and MS activities at this stage in life could help to maximise this and play a role in the prevention of osteoporosis. Both bone and muscle mass have been shown to decrease with age from the mid-20s, with an accelerated decline from age 50 onwards [13, 35]. This is apparent in both men and women, although hormonal changes associated with the menopause can further exacerbate the decline for women [13, 35]. Coupled with the fact that women, on average, have a smaller muscle mass than men, this means they tend to cross 'thresholds for independence' (the point at which a task cannot be completed independently) earlier [36].

Secondly, the proportions undertaking no MS sport and exercise activities over the age of 75 (84 % of men and 91 % of women) are concerning as muscle strength is of particular importance to older adults. One reason for this is because of the natural age-related decline of lean muscle mass (termed sarcopenia) [12]. Studies have estimated the decline to be around 2–4 % per year amongst those over 75 years, but the loss of strength can be 2–5 times faster than that because of other deleterious changes to muscle quality and neural factors [37]. This loss means that it can be muscle strength that is the primary limiting factor for functional independence [35], rather than aerobic PA. Low levels of muscle strength increase the risk of falling and sustaining a related injury, can lead to disability, and frailty [14, 38], all of which have implications for the individual, their carers, and the health services that support them. Strength training has been shown to be equally effective at increasing muscle strength in older adults as in younger adults, sometimes more so [39].

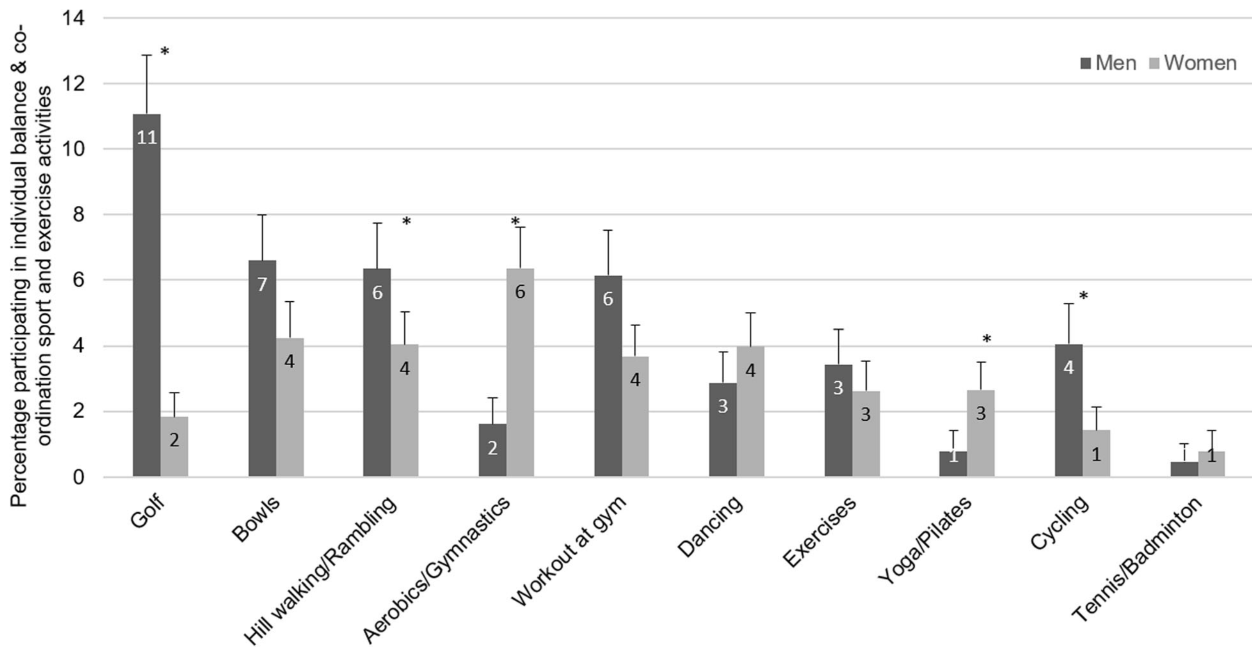

Fig. 4 Participation in balance & co-ordination sport and exercise activities, by gender. Weighted $n = 1347$ men, $n = 1687$ women. *significantly different between genders at $p < 0.0003$. Workout at gym includes weight training and exercise bike. Aerobics/Gymnastics includes 'keep fit' and 'dance for fitness'

Thirdly, the 18 % of men and 19 % of women that undertook some but not a sufficient number of sessions of MS sport and exercise activities per week are targets where successful intervention may be more likely. If related to the trans-theoretical model, then these individuals could be considered to be in the 'maintenance' phase (i.e. already undertaking a relevant behaviour) [40]. It is potentially easier for them to increase the frequency of this behaviour to the recommended levels than for those not currently undertaking any to start.

The differences by gender and age of participation in MS sport and exercise activities are similar to the overall participation levels for sport and exercise activities in Scotland [41]. From this we can infer that, for those activities that require a follow up question to confirm they are a relevant activity, the responses do not vary greatly by age or gender. This suggests that efforts to narrow overall participation gaps go some way to reducing the inequalities in the prevalence of the MS guideline. Our results also highlight hill-walking (for both genders) and golf (for men) as two activities where participation levels are maintained in the older age groups. These are potentially important intervention activities as it has been shown that sustained participation in MS exercise, starting at a young age, provides the greatest protection against sarcopenia [42].

Although the UK PA guidelines for adults apply from aged 19 [3], we included 16–18 year olds in our analyses as this aligns with UK health survey reporting and provides more useful information to policymakers. We have undertaken a comprehensive sensitivity analysis: their inclusion makes a ≤1 percentage point difference to the proportions doing no, some and sufficient MS exercise amongst 16–24 year olds and does not change any overall conclusions. The UK guideline relating to MS for 5–18 year olds is combined with that for vigorous intensity aerobic activity: 'Vigorous intensity activities, including those that strengthen muscle and bone, should be incorporated at least 3 days a week' [3]. Given that, if anything, these MS guidelines are greater than for those ≥19 years, we do not feel that this is an unfair misrepresentation.

Balance & co-ordination

We found that less than a fifth of older adults in Scotland (19 % of older men and 12 % of older women) met the BC guidelines in 2012–14. We found no differences in participation by gender, but a decline in the oldest two age groups. However, with such low levels of participation, we recommend that promotion efforts are aimed at all older adults rather than any specific groups.

Loss of the ability to balance is associated with a higher risk of falling and subsequent injury, which in turn can lead to loss of independence, illness, and premature mortality [43]. BC activities have been shown to be a critical part of an effective falls prevention programme [38]. One meta-analysis concluded that up to 42 % of falls could be prevented by a well-designed exercise programme that included BC activities [44].

Although the BC guideline applies to older adults at risk of falls [3], we included all older adults in our analyses as we were not able identify this ‘at risk’ group from the SHeS. This may have over- or under-estimated the proportions meeting the guideline. If those who are not at risk do not participate in any relevant activities then our estimates maybe lower than the true proportion. However, those who are not at risk may be more active, leading to an overestimation. We recommend that the target population of this guidelines is clarified, as this may hamper any co-ordinated effort to tackle the very low prevalence.

Strengths and limitations

This study is the first to provide detailed analysis of the two forgotten guidelines: MS and BC. We have used routinely collected data to describe the current prevalence levels and identify key groups most in need of intervention. This is important information to take to policymakers to support the case for addressing these issues at a population level. Policy makers in Scotland use the results from national surveillance instruments to make decisions on funding and strategy [45]. Therefore it is appropriate to use these same data in this analysis, as it has most relevance for future policy decisions. The face validity of the SHeS method of measuring prevalence of population meeting the MS and BC guidelines is questionable as it is limited to sport and exercise activities. Although this is more inclusive than other national approaches to measuring MS that are often restricted to weight training or activities that would be categorised in the domain of sport and exercise [34, 46, 47]. Activities such as heavy gardening and carrying heavy loads are not included despite being listed as example activities in the guideline document itself [3]. Another limitation of the SHeS questionnaire is that certain activities are grouped together or cover a wide range of activities (e.g. workout at gym/weight training/exercise bike, or exercises) and it is not possible to establish which of the activities was undertaken and what exactly they involved.

As with all surveys, errors may arise at any stage: design, data collection, processing, and analysis [48]. One that is difficult to account for is the self-report nature of the data. It is possible that the reported levels of MS and BC activities differ from the true levels [49]. We add our support to calls to reach an international consensus over which activities should count towards the guidelines, how best to measure them at a population level [34], how to ensure they are of sufficient intensity, and then to investigate validation methods so that the degree of error can be better understood. Other factors such as sampling error or non-response bias are mitigated by the weighting procedures that result in a nationally representative sample on key demographic variables (see Bromley et al. (2015) for further details [22]). However, there remains a degree of uncertainty around the estimates and this should be considered in their interpretation.

Conclusion

Our findings suggest that proportions meeting MS and BC guidelines are much lower than their aerobic counterpart. The promotion of PA should include efforts to increase the proportions meeting these forgotten guidelines. Particular efforts should be made amongst young women (for MS) and the older age groups (for MS and BC). Failure to do so could have important consequences as by 2031, the number of people over the age of 75 in Scotland is projected to rise by 75 % [50]. This will have implications for us as individuals and as a society if we do not change population levels of the many risk factors of ill health, of which strength and balance are two [4, 5, 16]. The most popular activities varied by gender and age and this should be considered when designing interventions. We also recommend further work on how best to monitor MS and BC activities at a population level.

Additional file

Additional file 1: Table S1. The results from multiple logistic regression investigating the effect of age group, gender, and their interaction on participation levels of muscle strengthening (weighted $n = 6873$ men, 7459 women). **Table S2**: The results from simple logistic regression investigating the effect of age group on participation in specific muscle strengthening sport and exercise activities, stratified by gender (weighted $n = 6873$ men, 7459 women). **Table S3**. The results from multiple logistic regression investigating the effect of age group, gender, and their interaction on participation levels of balance & co-ordination (weighted $n = 1347$ men, 1687 women). (XLSX 29 kb)

Abbreviations

BC: Balance & co-ordination; MS: Muscle strengthening; PA: Physical activity; SHeS: Scottish Health Survey

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Availability of data and materials

The dataset analysed during the current study are available in the UK data archive repository, SN 7594 http://dx.doi.org/10.5255/UKDA-SN-7594-1.

Authors’ contributions

TS, CF and NM designed the study. TS completed the analyses and drafted the manuscript. CF, NM and PK contributed to the interpretation and content of the final manuscript. All authors read and approved the final manuscript.

Competing interests

The authors have no competing interests to declare.

Consent for publication

Not applicable.

Ethics approval and consent to participate
This study has complied with all the requirements agreed in the UK Data Archive End User licence that applies to this dataset.

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7.6 Principal Findings

The three main findings of this work were that, in Scotland between 2012 and 2014 (1) compliance with the MSA recommendation was approximately half that of the MVPA recommendation (31% of men and 24% of women), (2) compliance with the BCA recommendation amongst older adults was very low (19% of older men and 12% of older women), and (3) that compliance with both the MSA and BCA recommendations decreased with age. In continuation from the definitions provided in the published article, the rest of this chapter uses the term ‘older adults’ to refer to those over 65 years.

7.7 Discussion of Main Themes

7.7.1 Comparison with other non-communicable disease risk factors

The results indicate that insufficient participation in MSA and BCA are amongst the most prevalent risk factors for NCDs for adults and older adults in Scotland (see Table 4). Insufficient MSA is nearly twice as prevalent as any other risk factor for men and women in Scotland. Insufficient BCA is over twice as prevalent as any other non-PA related risk factor. Taken alongside the potential health benefits already described, this is a strong indication that insufficient MSA and BCA participation places a large burden on the health system in Scotland and therefore should be addressed at a national policy level.

Table 4. Insufficient Muscle Strengthening and Balance and Co-ordination activities are the most prevalent Non-Communicable Disease Risk Factors Amongst Adults and Older Adults in Scotland in 2015.

Risk factor	Men			Women		
	≥16 years	65-74 years	≥75 years	≥16 years	65-74 years	≥75 years
Insufficient MSA[a]	69%	86%	91%	76%	88%	96%
Insufficient BCA[a, b]	N/A	81%		N/A	88%	
Insufficient MVPA[b]	33%	43%	58%	41%	62%	77%
Harmful alcohol consumption[c]	36%	37%	22%	17%	17%	7%
Current smoker[c]	22%	16%	9%	20%	14%	8%
Obesity (BMI≥30)[c]	28%	34%	22%	29%	33%	29%
No regular consumption of fruit or vegetables[c]	13%	10%	7%	9%	6%	5%

Note. MSA = muscle strengthening activity; BCA = balance and co-ordination activity; MVPA = moderate-to-vigorous physical activity; BMI = body mass index. [a]Data from present study; [b]Proportion calculated for the over 65s; [c]Data from "Scottish Health Survey 2015 Main Report", Campbell-Jack et al. (2016).

7.7.2 Prevalence and surveillance of muscle strengthening activities

As detailed in the published article (see discussion section on page 7), few other countries report prevalence data on MSA recommendation compliance. Since publication, a study found the prevalence amongst Finnish adults (≥18 years) was found to be 17.2% (95% CI: 16.9-17.6%; Bennie et al., 2017). This was within the range of other prevalence figures from the U.S., England, and Australia that were described in the published article (9-34%). All studies found higher levels of MSA participation in men compared to women, and in young adults compared to older adults (Bennie, Pedišić, van Uffelen, Charity, et al., 2016; Office of Disease Prevention and Health Promotion, 2014; Scholes & Mindell, 2013; Walker, Scarlett, & Williams, 2014).

As alluded to in the published article, differences in the questionnaires limit the cross-country comparisons. It has long been known that even small differences in question wording can greatly influence the response (Schuman & Presser, 1977; see also Appendix 11). It is therefore possible that some of the differences in national prevalence figures are due to the different measurement methods. A table showing the measurement instruments used in large cohort studies is included in Appendix 14. The main source of inconsistency is which activities 'count', raising concerns about the measures' content validity.

The root of the problem is likely to be the original evidence base for the recommendation. As discussed in Section 3.3, Bull and the Expert Working Groups (2010a) identified this when reviewing the literature. The Technical Report discussed how some experts felt heavy gardening should not count as a MSA, but there was a reasonable consensus for functional activities such as stair climbing and 'sit-to-stand' (Bull & the Expert Working Groups, 2010a). In the resultant CMOs' guideline document, weight training, working with resistance bands, carrying heavy loads, heavy gardening, push-ups, sit-ups, circuit training, and participation in 'recreational' sports like basketball or volleyball were given as examples (Department of Health, 2011). There was also a suggestion that 8-12 repetitions of an activity per session involving all the major muscle groups would be of significant benefit (Department of Health, 2011), based on the ACSM recommendations for older adults (ACSM et al., 2009). As not all of the example MSAs would be carried out in such a way that repetitions could be quantified (e.g. carrying heavy shopping), this hinders interpretation of the guideline rather than helps.

This led me to reflect on the competing priorities of this recommendation: to deliver a clear public health message to a population, to be based on robust evidence, and to be monitored by national surveillance. I am uncertain whether it is possible to design a recommendation for a complex health behaviour in an emerging field of research that can adequately satisfy all of these. In the case of the current MSA recommendation, the evidence base may not be able to support the specificity required for surveillance. Furthermore, such a recommendation may be too complex to be an effective public health message.

It is important to consider surveillance at an early stage in guideline development because any ambiguity is likely to have to be resolved by the survey contractors. This may not be the optimal situation as their expertise is often in survey methodology than subject-specific knowledge. In a situation where the evidence base is insufficient and/or unclear, it would be preferable for surveillance advice to be given alongside the recommendations. This would ensure that any necessary assumptions are made by those with the most expertise in the area. These are issues that I have discussed with Dr Charlie Foster, who is leading the next update to the U.K. PA guidelines.

7.7.3 Prevalence and surveillance of balance and co-ordination activities

Even in comparison to MSA, prevalence data relating to the BCA recommendation are scarce. This may be in part because not all nations have a quantified recommendation (e.g. Australia and the United States; see Table 5). Even amongst those nations that do, there is variation. Some recommend two, some three times per week, and some combine with MSA (see Table 5). Furthermore, it is not always obvious who the target population is. I decided to include all older adults ≥65 years in Study 2, although this could plausibly have under- or over-estimated the true value (see discussion in published article page 10). This is a further example of where surveillance advice developed alongside the recommendation would be beneficial.

Table 5. Current Balance-related Recommendations from Selected Countries and the World Health Organisation

Country or organisation	Recommendation
United Kingdom[a]	Older adults at risk of falls should incorporate physical activity to improve balance and co-ordination on at least two days a week.
Australia[b]	Older people should be active every day in as many ways as possible, doing a range of physical activities that incorporate fitness, strength, balance and flexibility.
Finland[c]	Muscle strengthening and balance training should be done two times per week.
United States[d]	Older adults should do exercises that maintain or improve balance if they are at risk of falling.
World Health Organisation[e]	Adults of this age group with poor mobility should perform physical activity to enhance balance and prevent falls on three or more days per week.

Note. [a]Department of Health (2011) [b]The Department of Health (2013) [c]The Urho Kekkosen Kuntoinstituuttisäätiö (UKK) Institute (2009) [d]U.S. Department of Health and Human Services (2008) [e]World Health Organisation (2010).

Putting measurement issues aside, the results of the present study are in line with others reporting BCA recommendation compliance in so far as prevalence is very low. In the study of Finnish adults mentioned in Section 7.7.2, the proportion undertaking ≥2 sessions of BCA per week was 6.7% (95% CI: 6.4-6.9%). However, their recommendation applied to adults of all ages. Given participation rates are known to decrease with age, one might assume that had they restricted their analyses to those over 65 years, the prevalence would be even lower. In a survey of older adults in Australia, 6% (95% CI: 5-7%) reported undertaking specific balance training (Merom et al., 2012). When the definition of BCAs was loosened to include other activities such as tai chi, dance, golf, bowls, and team sports, 15% (95% CI:14-16%) participated in ≥2 sessions week.

7.8 Implications for Policy

Figure 12 shows how this work has contributed to Scottish (and U.K.) policy and surveillance, and how it may continue to do so (for further details see Appendix 15). The most important potential implication for policy is the potential inclusion of MSA and BCA indicators on the ASOF. As indicated in Figure 12, I have evidence to suggest that sending a lay summary of Study 2 (see Appendix 16) to the head of policy in the Scottish Government Active Scotland Division was a catalyst for this process. This approach has been advocated by Brownson, Royer, et al. (2006) as a way of communicating academic research findings to policy-makers. It proved to be an effective strategy in this instance as I (along with Professor Nanette Mutrie MBE, Dr Paul Kelly, and Dr Claire Fitzsimons) were able to meet the analyst with responsibility for PA at the time (Julie Guy) to discuss the findings. As a result of this meeting, I was asked to develop a proposal to add indicators for MSA and BCA (and ST, as will be discussed in Chapter 8) to the ASOF (see Appendix 17). This proposal was considered alongside a wider review of the ASOF; Professor Nanette Mutrie MBE has been providing regular input to this process.

It is interesting and important to consider why the publication of Study 2 was able to have this influence, as it may inform the design, analysis, and knowledge exchange of future academic research. The main message of Study 2 (that the prevalence of MSA and BCA recommendation compliance is low amongst adults in Scotland) was already in the public domain via the SHeS Annual Reports (Bromley, 2013; Gill, 2015; Hinchliffe, 2014). The novel, more detailed participation results have barely been considered (to the best of my knowledge).

I believe there are three factors that aligned that enabled the proposal for additional ASOF indicators to be considered. Firstly, and most importantly, the publication provided an opportunity to highlight the issue. This occurred through the direct communication with the Scottish Government described above, but also through undertaking national radio and newspaper interviews resulting from the University of Edinburgh press release. Secondly, undertaking this research increased my knowledge of the topic area and enabled me to be a more authoritative advocate for including MSA and BCA in national policies. Also, the publication of the results in a peer-reviewed journal added a level of quality assurance that I believe was beneficial when communicating with policy-makers. Neither these first two points would have been the case had I simply summarised the previously published data. Thirdly, there was a conducive external environment for considering the proposal. I had built up professional relationships with key policy-makers during an internship at the Scottish Government (May-July 2016), and through communication on issues relating to Study 1. Alongside my own knowledge exchange activities, trusted PA experts Professor Nanette Mutrie MBE and Dr Andrew Murray regularly shared the findings of Study 2 with the National Steering Group Evidence Sub-group, the Minister for Public Health and Sport, and the CMO. Finally, it was a timely proposal as there was a wider review of the ASOF was underway.

It is possible that more detailed participation analyses will have relevance in the future when the focus shifts to which sub-groups of the population are most at risk, and what might suitable interventions involve. This has parallels with the Behavioural Epidemiology Framework that suggests research relating to intervention design should occur once basic prevalence figures have been established (Sallis, Owen, & Fotheringham, 2000). It is entirely logical that research use may also occur in this sequence.

In comparison with Figure 11 (the comparable figure for Study 1), the process appears less complex, with fewer stakeholders involved, and fewer interactions between activities. This chimes with my experience of the process. There are a number of possible reasons for this. Compared with MVPA, there are fewer organisations that are involved in MSA and BCA promotion and so the initial target audience was more limited. Secondly, this paper was published about 10 months after the previous and therefore there has been less time for the knowledge exchange activities and interactions between stakeholders. Even so, the process has again indicated that policies are developed as a result of many contributing factors, many of which are outside a researcher's control (Bowen & Zwi, 2005; Nutbeam, 2004).

7.9 Implications for Surveillance

As a result of Study 2's publication, I was invited to be on the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance (meeting in London, July 2017). I was invited specifically to discuss the surveillance issues surrounding the MSA and BCA recommendations. As the contribution I made also included work undertaken as part of Study 4, further discussion of this impact is included in Chapter 9.

As Figure 12 shows, a more minor implication for surveillance was that during my thorough derivation of variables for Study 2, I noticed an error on the publically available SHeS 2012-14 datasets stored in the U.K. Data Archive. This meant that the figures previously published in the SHeS reports were a few (all cases less than five) percentage points too low. I shared my corrected analysis code with the relevant teams at the Scottish Government and ScotCen and the archived datasets were corrected.

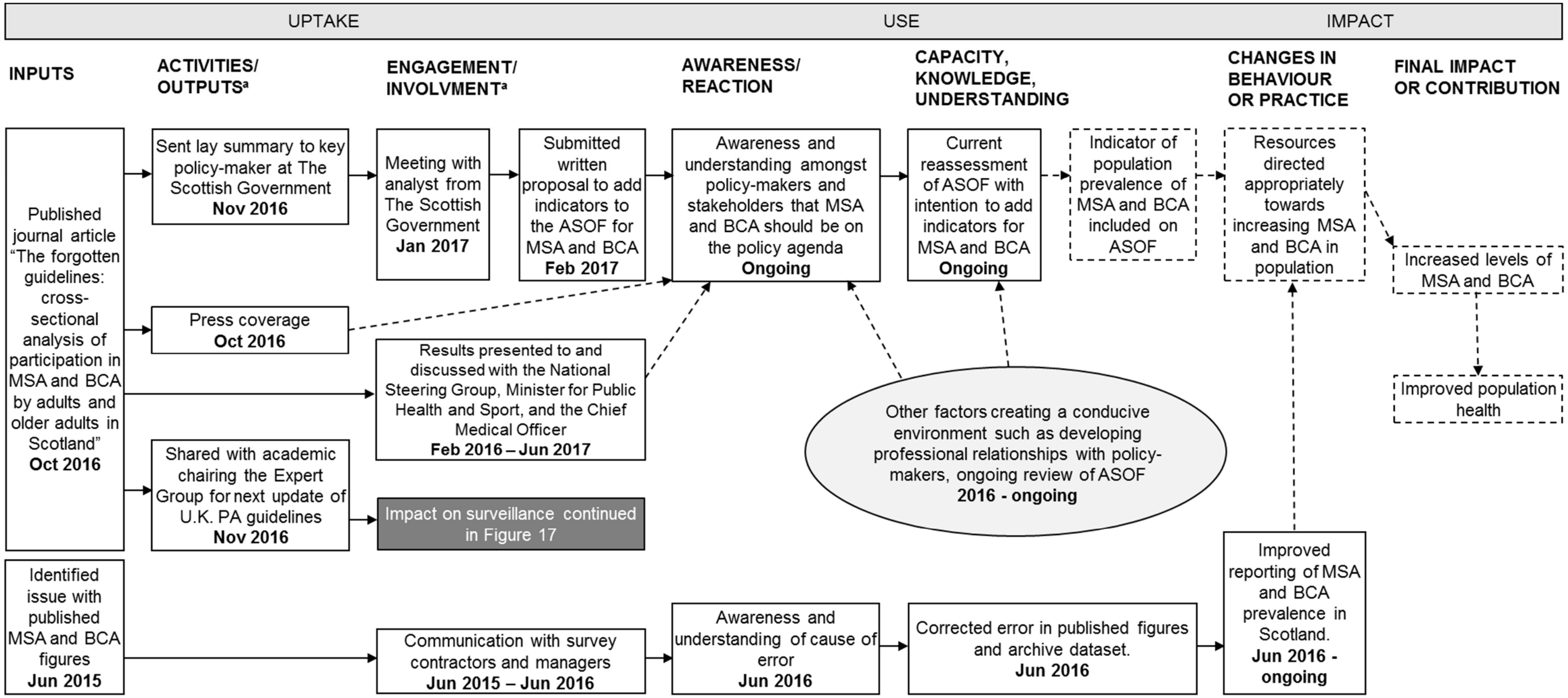

Figure 12. Tracing the Impact of Study 2.

Based on the Pathway for Impact from Morton (2015). Continuous arrows represent connections that evidence supports (see Appendix 15); dashed lines represent plausible connections. [a]Activities/Outputs covers broad knowledge exchange activities, Engagement/Involvement covers user interactions. ASOF = Active Scotland Outcomes Framework; BCA = balance and co-ordination activity; MSA = muscle strengthening activity; PA = physical activity.

7.10 Strengths and Weaknesses

As with the previous chapter, many of the strengths and weaknesses of the work were discussed in the published article. Table 3 summarised the ways the limitations of previously published figures have been addressed in the present study. Therefore, this section focusses on the learning points taken from Study 1, and on the learning to be taken forward to future studies in the thesis.

There were four main learning points from Study 1 that were incorporated into the present study: (1) combining several survey years to give a larger total sample size, (2) including the detailed statistical results in supplementary tables, (3) the presentation of 95% CIs and standard errors where appropriate, and (4) interpreting conclusions based on the combination of CIs and *p* values. Doing this improved the study quality in a number of ways.

The larger sample size gave greater certainty to the estimates, which was particularly important in some sub-groups where numbers were small. Moving the detailed tables to 'supplementary material' meant all information was still available but there was space in the paper for informative figures that were widely shared on social media. This increased the reach of the paper and made reading the article easier for both academics and lay audiences. Interpreting the results based on both the CIs and *p* values helped to focus on the key difference between men and women in MSA recommendation compliance in the youngest age group, rather than one-off significant *p* values of interaction effects detracting from the main message. However, in hindsight, the *p* values were superfluous as they did not add further information to CIs. Furthermore, after correcting for multiple comparisons, using *p* values to determine the overall message from the data was somewhat meaningless as the criteria for statistical significance became so stringent (α-level of 0.0003; see page 4 of the published article).

The inclusion of interaction effects was also influenced by my learning from Study 1 (see Section 6.7). They allowed for useful and informative comparisons by both age and sex, but they made the results difficult to interpret for both an academic and lay audience. This was because the main comparisons are made for the reference group; any between group comparisons needed to factor in the interaction term. It would have been preferable to undertake a statistical test for the overall effect, for example using the Likelihood Ratio on the logistic regression models. However, this is not advised when analysing complex samples because the clustering and stratification can violate key assumptions (Heeringa et al., 2010). This was an important learning point as it showed that trying to make sure academic research is accessible to a policy-audience is not limited to selecting a relevant research question but involves decisions at all stages of the study.

7.11 Chapter Summary

In conclusion, this work has raised awareness and understanding amongst policy-makers of the need to address MSA and BCA at a national policy level. Proposals to add indicators for the ‘forgotten guidelines’ are currently being considered; the publication of Study 2 was instrumental in this process. The results also highlighted young women (for MSA) and older adults (for MSA and BCA) as groups where efforts should be prioritised. Through this work, I realised the importance of considering surveillance alongside guideline development, and have taken steps to ensure this occurs at the next U.K. update.

Chapter 8: Study 3 – Differences by Age and Sex in the Sedentary Time of Adults in Scotland

This chapter presents work relating to Study 3: an investigation into the ST of adults in Scotland. Study 3 was published in the Journal of Sports Sciences (June 2017) and is included as part of this chapter. As with the two previous chapters, it is preceded and followed by additional paragraphs expanding upon the content of the paper.

I led all the work, undertook all analyses, and wrote the published paper and this chapter. Dr Claire Fitzsimons, Dr Paul Kelly, and Professor Nanette Mutrie MBE acted in a supervisory capacity at all stages.

8.1 Sedentary Behaviour as an Independent Risk Factor for Ill Health

In Section 3.3.4, I outlined the evidence that supported a recommendation on SB in the 2011 U.K. CMOs' PA guidelines. This section discusses the recent evidence relating to ST as a risk factor for ill-health independent of MVPA, as justification for Study 3's focus on the prevalence of ST in amongst adults in Scotland. There are three lines of argument: (1) ST and a lack of MVPA are behaviourally distinct, (2) associations with health outcomes have been demonstrated, independent of MVPA levels, and (3) the biological mechanisms through which ST and MVPA affect health appear to be different.

On the first point, it is clear that one can meet the MVPA recommendation (approximately 30 minutes per day) yet still sit for >10 hours per day; being 'active' and 'sedentary' are not mutually exclusive. Owen, Sparling, Healy, Dunstan, and Matthews (2010) used nationally representative accelerometer data from the U.S. to demonstrate this.

Regarding the second point, since the 2011 U.K. CMOs' PA guidelines, meta-analyses have concluded that high ST is associated with a 24% (95% CI: 9-41%) increased risk of ACM, 18% (95% CI: 11-26%) increase of CVD mortality, 17% (95% CI: 11-24%) increased of cancer mortality, and 91% (95% CI: 64-122%) increase of type 2 diabetes, compared to low ST (Biswas et al., 2015). The range of health outcomes that ST might influence has expanded with reviews published on metabolic syndrome (Edwardson et al., 2012), anxiety (Teychenne, Costigan, & Parker, 2015), cognitive function (Falck, Davis, & Liu-Ambrose, 2017) and physical function amongst adults over 60 years (Copeland et al., 2017). Risk factors such as blood pressure, waist circumference, body mass index (BMI), high-density lipoprotein cholesterol, and insulin sensitivity have also shown independent (from MVPA) cross-sectional and prospective associations with total ST (Brocklebank, Falconer, Page, Perry, & Cooper, 2015; Knaeps et al., 2016). However, it is worth noting most prospective studies rely on self-report or accelerometry data, both of which have limitations when measuring total ST (Kang & Rowe, 2015). Adjustment for BMI in these studies is variable which is important for isolating the effects of total ST on health.

Most of the studies cited above or included in the meta-analyses adjusted for MVPA. Section 11.1 covers the most appropriate statistical methods to do this, however, it is worth noting at this stage that MVPA may modify the association between ST and some health outcomes. This means that the association differs at different levels of MVPA. The results of Ekelund et al. (2016) are an example of this. Ekelund et al. (2016) found that higher levels of ST were associated with an increased risk of ACM and CVD mortality across all but the top quartile of MVPA (again, Section 11.1 will discuss this study in greater detail). This indicates that high

ST is an important health concern for the majority of adults, and therefore is also of interest to policy-makers in Scotland.

Despite the strong meta-analysis results from Biswas et al. (2015), the literature is not wholly in agreement (van der Ploeg & Hillsdon, 2017). It is plausible that the modifying effect of MVPA could explain some of the contradictory results of studies investigating the effects of ST on ACM. For example, Pulsford, Stamatakis, Britton, Brunner, and Hillsdon (2015) did not find evidence of a relationship between ST and ACM in a cohort of British civil servants. However, this cohort was more active than the general population (the reported sample mean was 90 minutes of daily MVPA not including substantial volumes of walking; 2012-15 SHeS respondents reported a mean of approximately 45 minutes per week of MVPA including walking). Therefore, the sample of British civil servants could have been undertaking enough MVPA to attenuate or eliminate the hazards of high ST. It is worth noting that some leading researchers remain sceptical as to the independent associations of ST and health, citing residual confounding, causality assumptions, and measurement errors as plausible reasons for why associations are found (van der Ploeg & Hillsdon, 2017).

On the third point, some of the physiological mechanisms through which total ST may affect health have been shown to differ from those underlying MVPA-related adaptations. To prevent repetition, the reader is referred back to Section 3.3.4, where these were discussed in more detail. Recent evidence to support these earlier findings has focussed on the ‘risk factor gap’ (Carter, Hartman, Holder, Thijssen, & Hopkins, 2017). This is the concept that there is still an unexplained element of vascular health that MVPA does not account for (Carter et al., 2017). Some have suggested that high ST could be one answer, given the increasing evidence showing negative effects of high ST on vascular function after adjustment for MVPA (see Carter et al., 2017 for summary).

In conclusion, a study investigating the ST of adults in Scotland, regardless of their MVPA level, is justified based on the current research evidence. The evidence suggests that a sizeable proportion of adults in Scotland are increasing their risk of ill health due to their levels of ST. Therefore, this should be of interest to policy-makers.

8.2 Developing Previous Analyses

Previous chapters have emphasised the disconnect between the 2011 U.K. CMOs' PA guidelines and Scottish policy. Like MSA and BCA, the recommendation on SB had not been transferred into any strategic documents (The Scottish Government, 2014a, 2014c). However, unlike MSA and BCA, there was considerable awareness amongst policy-makers of the potential harmful effects of high ST. I experienced this first-hand whilst undertaking an internship at the Scottish Government (see Section 1.3 for timeline). This is not altogether surprising as studies such as that of Ekelund et al. (2016) received considerable media attention (Altmetric, 2017). Although, as content analysis by Chau et al. (2017) have shown, this did not always provide the full story.

Prior to the publication of Study 3, there was limited information on the total ST of adults in Scotland. The only published nationally representative statistics were for leisure ST only (Bromley, 2013; Gill, 2015; Hinchliffe, 2014). This comprised of the reported daily (weekday and weekend day) total durations of TV and/or screen time and 'any other leisure ST' (see Section 4.4.4 for details on the questionnaire and page 1 of the published article for description of previously published statistics). The omission of ST at work was problematic for policy-makers. When on my internship, I was asked to create an infographic analysing and presenting the data relating to all the 2011 U.K. CMOs' PA guidelines (see Appendix 18). Although not experts in the field, the measure of leisure ST did not pass their face validity tests for a suitable summary statistic.

Therefore, Study 3 aimed to investigate the total ST (i.e. including ST at work) of adults in Scotland. I anticipated being able to share the analysis code with the relevant people such that future reporting would include ST at work. I believed this could be influential in the development of policies for similar reasons described in the previous chapter: producing my own analyses and publishing a peer-reviewed paper gave me a personal opportunity to raise the issue and present solutions (i.e. include an indicator on the ASOF). A secondary research question was to investigate the relative contributions of the categories of behaviours. This information is helpful to policy-makers to know where best to focus policies and intervention efforts.

I chose to investigate differences by age and sex as these were the two factors investigated in the previously published analyses. Given that both are known to be associated with work status (Office for National Statistics, 2017), it was plausible that the trends seen in leisure ST would not hold when ST at work was considered. I considered investigating indicators of socio-economic position but concluded that age and sex were of higher priority. Age and sex are the characteristics that all health behaviours are reported by (Campbell-Jack et al., 2016), and so any initial analyses are best undertaken using these covariates. Adding a third covariate that was most appropriately described using four or five categories would have left the sub-groups too small to make precise estimates. The decision to stratify by work status was taken after inspection of the data as it was clear there were interaction effects. Table 6 shows the ways in which the present study addresses the limitations of the previously published figures.

Table 6. Differences Between Study 3 and Previous Literature

Element of study method or study attribute	2012-15 SHeS Annual Reports[a]	Strain, Kelly, Mutrie, and Fitzsimons (2017)
Scottish-specific data	✓	✓
Mean total daily (weekday and weekend day) ST by sex	Non-occupational only	✓
Mean total daily (weekday and weekend day) ST by age-group	Non-occupational only	✓
Interaction terms (age*sex) included	X	✓
Stratification by work status		
Statistical tests performed	X	✓
Relative contributions of behaviour categories investigated, by age and sex	X	✓
Peer reviewed publication	X	✓

Note. [a]2012: Bromley (2013); 2013: Hinchliffe (2014); 2014: Gill (2015).

8.3 Published Article

Study 3 was published by Taylor & Francis in the Journal of Sports Sciences published online in June 2017 (http://dx.doi.org/10.1080/02640414.2017.1339904). The accepted manuscript version is included in this thesis, as licensed under the 'Green Open Access' agreement. As per the embargo agreement, this will be made available on the University of Edinburgh repository 18 months after article publication (December 2018). The supplementary tables are included in Appendix 19; the information in the supplementary file was already covered in Appendix 8).

Differences by age and sex in the sedentary time of adults in Scotland

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Differences by age and sex in the sedentary time of adults in Scotland

Previous nationally-representative research in Scotland found a j-shaped relationship between age and leisure sedentary time (ST): a decrease from young to middle-age, before rising steeply in older-age. This study investigated the effects of age and sex on weekday (including work) ST for all adults and stratified by work-status, and on weekend day ST. Differences in the relative contributions of component behaviours were also investigated. Responses from 14,367 adult (≥16 years) 2012-14 Scottish Health Survey participants were analysed using linear regressions. We found no j-shaped relationship between age and weekday ST. Instead, only 16-24 year olds reported lower levels than those over 75 years (6.6 (95% CI: 6.3-6.9) compared to 7.4 (95% CI: 7.2-7.6) hours/day; p<0001). The j-shape was only evident in the stratified analysis amongst women not in work, and for weekend day ST for all groups. For those in work, work ST accounted for 45% of weekday ST. Television/screen ST made up over half of leisure ST on weekdays and weekend days, regardless of sex, age, or work-status. These results challenge our understanding of how ST varies by age. Interventions to reduce ST should consider differences in the relative contributions of ST behaviours by age and work-status.

Keywords: sedentary; survey; sex; age; adults

Introduction

Sedentary time (ST) is defined as time spent in any waking activity which is undertaken in a sitting or reclined posture and has an energy expenditure of ≤1.5 metabolic equivalents of task (METs) (Sedentary Behaviour Research Network, 2012). There is growing evidence to suggest that high levels of ST (>7-10 hours/day) are associated with an increased risk of all-cause mortality, cardiovascular disease, type 2 diabetes, and some cancers amongst adults (Biswas et al., 2015; Chau et al., 2013; Pandey et al., 2016). These harmful effects can be attenuated by physical activity, but are only eliminated amongst those who undertake very high volumes (approximately 60-75 minutes of moderate intensity physical activity per day) (Ekelund et al., 2016). There is also evidence to suggest that not all sedentary behaviours have equal health impacts: high levels of television (TV) viewing often show stronger negative associations than total ST with health outcomes such as type 2 diabetes and obesity (Hu, Li, Colditz, Willett, & Manson, 2003), and cancer (Schmid & Leitzmann, 2014). It is plausible that this is due to other concurrent unhealthy behaviours such as snacking on calorie dense foods (Jeffery & French, 1998; Meyer et al., 2008).

Currently, the UK physical activity guidelines recommend that people of all ages minimise the amount of time they spend being sedentary for extended periods (Department of Health, 2011). In Scotland, average daily ST is measured by the Scottish Health Survey (SHeS). Adult (≥16 years) participants are asked to report how much time they spend in sedentary behaviours, grouped into three categories: sitting at work, leisure TV/screen time, and any other leisure sedentary behaviours (such as eating a meal, reading, or listening to music). Participants are asked to respond based on their ‘typical’ working day (if applicable). For TV/screen ST and other leisure ST they are asked to report for an average week and weekend day (Bromley, Campbell-Jack, & Hinchliffe, 2015).

Although these data have been collected annually since 2012, limited summary statistics have been reported. The 2012 SHeS annual report published the mean hours of reported ST on weekdays and weekend days by age and sex, but only including leisure TV/screen ST and other leisure sedentary behaviours. Averages ranged between 4.6–7.6 hours/day, and there was a clear j-shaped trend with age for men and women: a decrease from young to middle-age, before rising steeply in older-age (Bromley, 2013). The Health Survey for England (HSE) found very similar results, using the same survey items (Scholes & Mindell, 2013).

The first research question is: do the relationships between ST and age and sex remain the same when work ST is included in the measure of weekday ST? Not including work ST could be distorting our understanding of the levels of ST amongst office workers in Scotland who, estimates suggest, spend 65-75% of their work time sitting down (Buckley et al., 2015). As the workplace is already a focus of many ST interventions (Shrestha et al., 2016) it is vital to include time spent sitting there in the national prevalence statistics.

The second research question is: how do the relative contributions of the categories of behaviours (sitting time at work, leisure TV/screen ST, and any other leisure ST) to weekday and weekend day ST vary by age and sex? This information is important to tailor and direct interventions to reduce ST. Given the potential differential health effects of the behaviours, further understanding of how they vary by age and sex for adults in Scotland is warranted.

Methods

Data source

We acquired the 2012-2013-2014 SHeS combined dataset from the UK Data Archive on 17th December 2015 (ScotCen Social Research, 2015). After weighting, the dataset is nationally representative of the population living in private households in Scotland from 2012 to 2014. Data are collected via an interviewer-led computer assisted interview. For more details see the SHeS Technical Report (Bromley et al., 2015).

Assessment of sedentary time

Adult participants (≥16 years) were asked to report the duration of sedentary behaviours under three categories: (i) time spent sitting at work on a typical day, (ii) leisure time spent sitting watching TV or other screen devices on a typical weekday and weekend day, (iii) time spent in other leisure sedentary activities such as eating a meal, reading, or listening to music, on a typical weekday and weekend day (see Supplementary File 1 for the full questionnaire). Participants were instructed not to double-count the behaviours. We assumed that a typical work day was a weekday. Typical weekday ST was calculated as the sum of (i) and the weekday responses to (ii) and (iii). This relies on the assumption that a weekday is a working day. There are no official statistics for Scotland that support or discredit this assumption, however, the European Working Conditions Survey concluded that working a five-day week from Monday to Friday was still the norm for most Europeans (European Foundation for the Improvement of Living and Working Conditions, 2012). Typical weekend day ST was calculated as the sum of the weekend day responses to (ii) and (iii). Relative contributions of the categories of behaviours to weekday and weekend day ST were calculated for each individual as the proportion of time spent in each category out of the respective totals.

We undertook a comprehensive assessment of the validity and reliability evidence of the ST questions in the SHeS using the Edinburgh Framework as a guide (Kelly, Fitzsimons, & Baker, 2016). We found that limited high-quality evidence existed, but there were no major concerns (a summary of this work is included in Supplementary File 2). We acknowledge that the inherent limitation of self-reported data is the reliance on the participants' recall, however, this is currently the optimal way of collecting nationally-representative data on total and behaviour-specific ST for adults in Scotland (Dall et al., 2017).

Sample

There were 14,367 adult participants in the 2012-13-14 SHeS. Due to missing data in one or more of the component variables, 98 cases were excluded from the weekday analyses and 77 from the weekend day analyses (<1% of total cases). In line with previous similar research (Bennie et al., 2013; Bennie et al., 2016), cases were excluded if their total exceeded 16 hours per day as these were considered to be outliers (136 cases for weekdays and 111 cases for weekend days; <1% of total cases). This left 14,133 cases in the weekday analyses and 14,179 cases in the weekend day analyses. These were weighted to make the sample nationally-representative of adults living in private households in Scotland (see Table 1).

Statistical analyses

We used multiple linear regressions to investigate the differences in weekday and weekend day ST by 10-year age band (from age 16), sex, and any interaction between these terms. We repeated these analyses stratified by work status (whether undertaken paid or self-employed work in four weeks prior to interview (57% of the sample), or not), and for the relative and absolute contributions of the categories of sedentary behaviours. Only one regression analysis was performed on the relative contributions of the categories of behaviours of weekday ST amongst non-workers and for weekend day ST. This was because the two categories were reciprocals. The reference categories were males and those over the age of 75 years as these were the groups that previous work had identified as sitting the most (Bromley, 2013). The analyses stratified by work status were an exception to this as there were not sufficient numbers in the oldest age group amongst those in employment to make meaningful comparisons. In this case we used 65-74 year olds as the reference age group.

There was strong evidence of digit preference for all the time variables as over 99% of responses ended in the digits 0 or 5; (Beaman, Vaske, Donnelly, & Manfredo, 1997; Kelly, 2013; Rietveld, 2001). Despite this, the underlying distributions of the model residuals was approximately normal, with slight evidence of leptokurtis. Recommended strategies for dealing with these issues such as grouping observations into categories (Forthofer, Lee, & Hernandez, 2007), or performing transformations, did not alter the distribution pattern of the residuals and therefore the data were analysed as planned.

All analyses were performed in STATA version 14. Due to the stratified clustered sampling design (see Bromley et al. (2015)), we used Taylor-Series linearisation methods to estimate the variance. This was necessary because when a sample is clustered and/or stratified, the observations are not independent and identically distributed (an assumption of normal variance estimation techniques) (Heeringa, West, & Berglund, 2010). We have not used any cut-off to determine statistical significance but have presented the 95% confidence intervals (CI) and p-values (see Supplementary Tables), and have interpreted the results based on these factors and overall trends.

Results

Weekday sedentary time for men and women, by age group

Figure 1 and Table 1 show the mean reported typical weekday ST of adults in Scotland. There was strong evidence to suggest that, for men, the youngest age group (16-24 year olds) reported less ST than the oldest age group (over 75 years; 6.6 (6.3-6.9) compared to 7.4 (7.2-7.6) hours/day; $p<0.001$). There was some evidence to suggest the middle-age groups reported higher levels of ST than the oldest age group; 45-54 year olds reported 7.8 (7.6-7.8) compared to 7.4 (7.2-7.6) hours/day ($p=0.007$). However, we should be cautious not to over-interpret a 0.4 hour (24-minute) difference. For women, there was strong evidence to suggest that the over 75s reported more ST than all other age groups (ranging between 6.6-6.9 (6.4-7.1) hours/day for 16-74 year olds compared to 7.4 (7.2-7.6) hours/day for the over 75s. We reached this conclusion as there was no evidence for a main effect of sex, but the p-values and confidence intervals suggested a main effect for 16-24 year olds and interaction effects between ages of 25 and 74. There was no difference in the reported weekday ST of men and women over the age of 75 years, but the interaction effect p-values suggest that women reported less ST than men between the ages of 25 and 74 (all $p<0.05$). See Supplementary Table 1 for regression results.

Table 1. The mean (and 95% confidence intervals) for total and for the categories of behaviours of weekday sedentary time, for all adults and stratified by work status.

	All adults		Adults in work				
Age group	weighted n	Mean hours of total weekday sedentary time (95% confidence interval[a])	weighted n	Mean hours of total weekday sedentary time (95% confidence interval[a])	Mean hours of total sitting time at work (95% confidence interval[a])	Mean hours of weekday TV/screen time (95% confidence interval[a])	Mean hours of weekday other leisure sitting time (95% confidence interval[a])
16-24	971	6.6 (6.3, 6.9)	538	6.8 (6.4, 7.2)	1.9 (1.6, 2.3)	3.3 (3.0, 3.6)	1.6 (1.4, 1.7)
25-34	1074	7.7 (7.4, 8.0)	896	7.8 (7.4, 8.1)	3.6 (3.3, 3.8)	2.8 (2.6, 3.0)	1.4 (1.3, 1.5)
35-44	1075	7.6 (7.4, 7.9)	924	7.7 (7.4, 7.9)	3.9 (3.6, 4.1)	2.5 (2.4, 2.6)	1.3 (1.2, 1.4)
45-54	1270	7.8 (7.6, 8.0)	1017	7.8 (7.6, 8.1)	3.7 (3.5, 4.0)	2.7 (2.6, 2.8)	1.4 (1.3, 1.4)
55-64	1052	7.7 (7.4, 7.9)	651	7.9 (7.6, 8.2)	3.5 (3.3, 3.7)	2.9 (2.7, 3.0)	1.5 (1.4, 1.6)
65-74	803	7.2 (7.0, 7.4)	123	7.7 (7.3, 8.2)	2.9 (2.5, 3.3)	3.2 (3.0, 3.5)	1.6 (1.5, 1.8)
75+	524	7.4 (7.2, 7.6)	14	6.5 (5.1, 7.8)	1.8 (1.0, 2.6)	2.4 (1.9, 2.9)	2.2 (1.8, 2.7)

	Adults not in work			
Age group	weighted n	Mean hours of total weekday sedentary time (95% confidence interval[a])	Mean hours of weekday TV/screen time (95% confidence interval[a])	Mean hours of week day other leisure sitting time (95% confidence interval[a])
16-24	433.6	6.2 (5.9, 6.6)	4.5 (4.2, 4.8)	1.8 (1.6, 1.9)
25-34	178.5	7.3 (6.6, 7.9)	4.9 (4.3, 5.4)	2.4 (2.0, 2.8)
35-44	151.3	7.3 (6.7, 8.0)	5.0 (4.4, 5.6)	2.3 (2.0, 2.7)
45-54	253.3	7.7 (7.2, 8.2)	5.3 (4.9, 5.8)	2.4 (2.1, 2.7)
55-64	400.7	7.3 (7.0, 7.6)	5.0 (4.7, 5.3)	2.3 (2.1, 2.5)
65-74	680.2	7.1 (6.9, 7.3)	4.5 (4.3, 4.7)	2.6 (2.4, 2.7)
75+	509.6	7.4 (7.2, 7.7)	4.3 (4.1, 4.5)	3.1 (2.9, 3.3)

[a]95% confidence intervals calculated using Taylor Series Linearisation method to account for complex survey design.

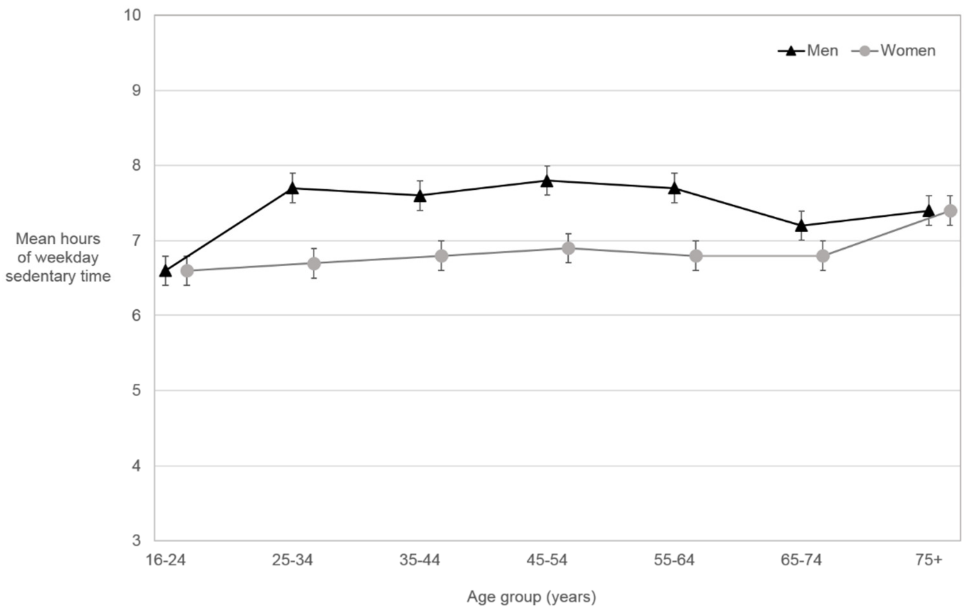

Figure 1. Weekday sedentary time for adults in Scotland, by age group and sex.
Figure 1 caption. Error bars represent the 95% confidence interval

Weekday sedentary time, stratified by work status

Figure 2 and Table 1 show the mean reported weekday ST of adults in Scotland, stratified by work status. For those in work (Figure 2A), the trends were similar to those for all adults, except that there was no evidence of any differences between the sexes. The youngest age group (16-24 year olds) were the only age group where there was evidence to suggest lower levels of reported ST compared to 65-74 year olds (6.8 (6.4-7.2) for men and women compared to 7.3-7.7 (6.7-8.2) hours/day; p=0.003). For those not in work (Figure 2B), there were clear differences by sex (relevant interaction effect p-values between ages of 25-65 years all ≤0.001). For men, again, it was only the 16-24 year olds where there was strong evidence to suggest lower levels of reported ST compared those over 75 years (6.3 (5.9-6.6) hours/day compared to 7.4 hours/day; p<0.001). However, for women, a j-shaped pattern was evident where those aged 25-44 years reported the lowest levels of ST (5.2-5.4 (4.9- 5.6) hours/day), but the highest levels of reported ST were amongst those over the age of 65 (6.7-7.4 (6.5-7.6) hours/day). See Supplementary Table 1 for regression results.

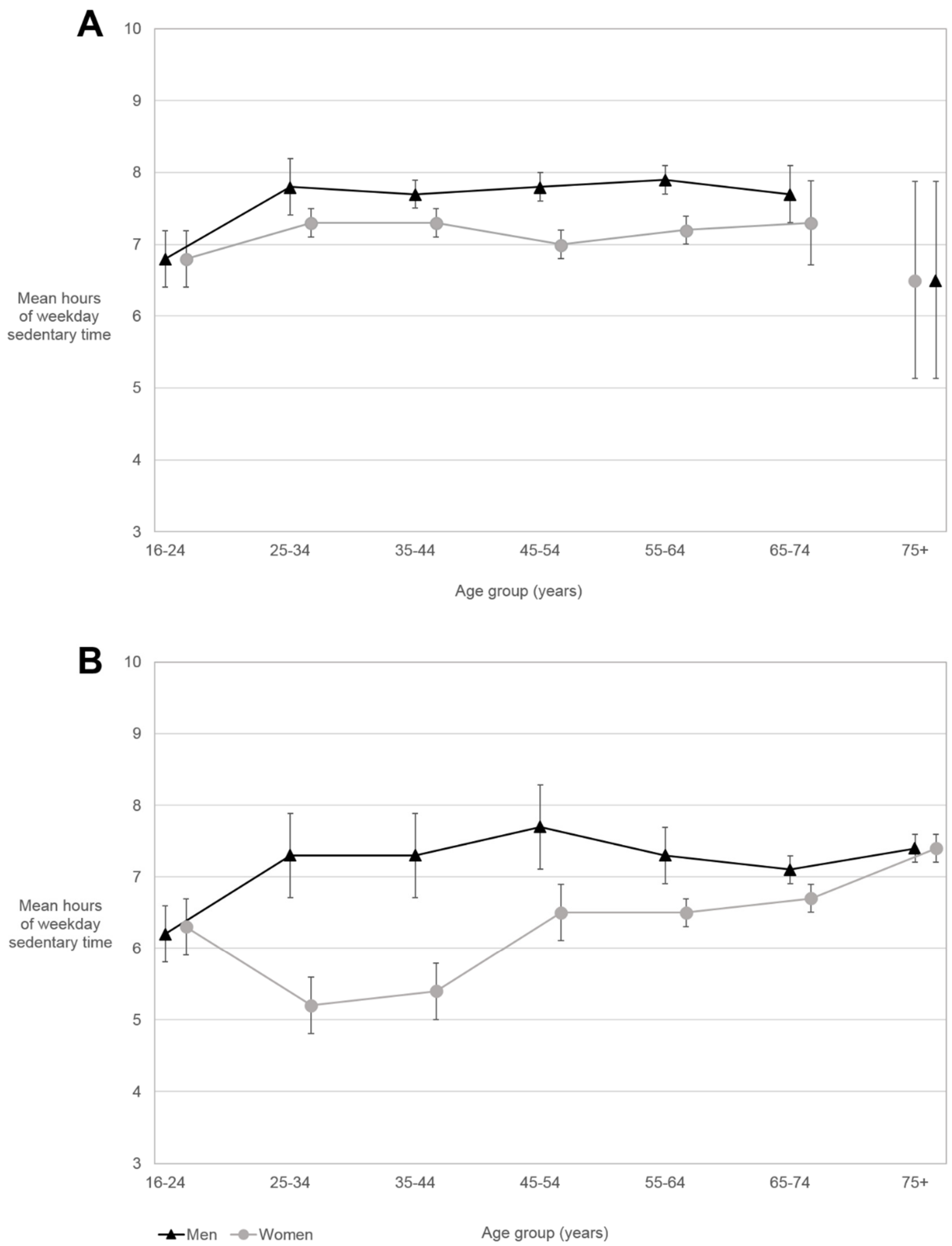

Figure 2. Weekday sedentary time for adults in Scotland, by age group and sex, stratified by work status.

Figure 2 caption. A: Those in work in the four weeks prior to interview. B: Those not in work in the four weeks prior to interview. Error bars represent the 95% confidence interval.

Weekend day sedentary time

Figure 3 and Table 2 show that the association between reported weekend day ST and age group followed a j-shaped pattern for both sexes. Those aged 25 to 54 reported the lowest levels of weekend day ST (5.2-5.7 (5.0-5.9) hours/day). There was strong evidence to suggest that those over the age of 75 reported the most ST (7.3-7.4 (7.1-7.7) hours/day compared to 5.2-6.9 (5.0-7.1) hours/day for 16-65 year olds; all p≤0.001). See Supplementary Table 2 for regression results.

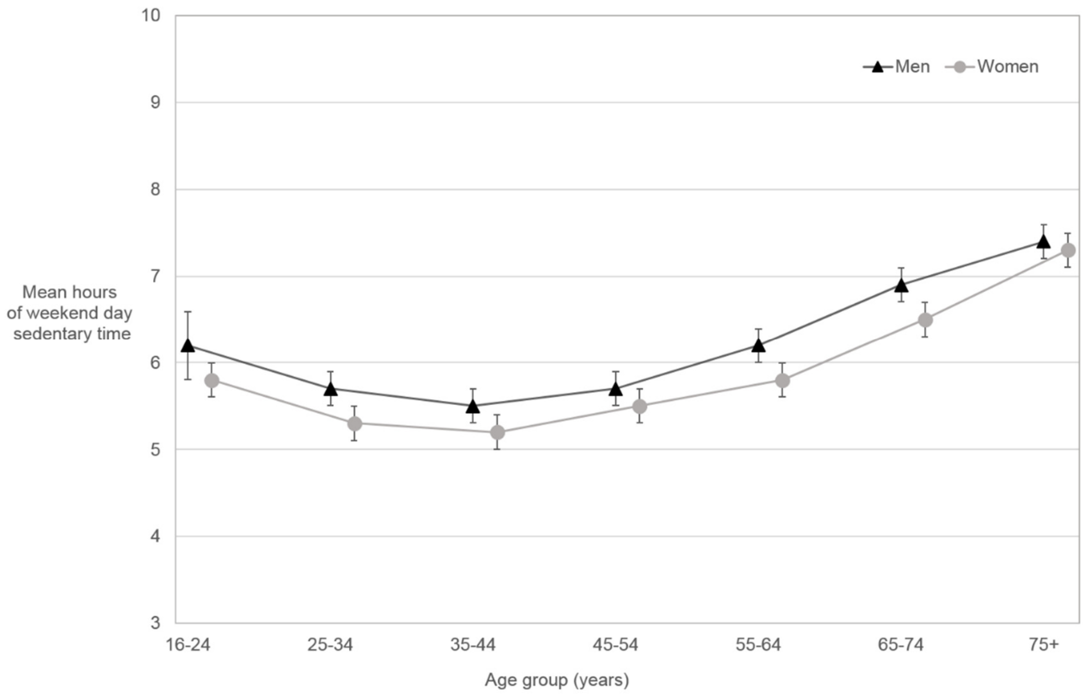

Figure 3. Weekend day sedentary time for adults in Scotland, by age group and sex.
Figure 3 caption. Error bars represent the 95% confidence interval.

Table 2. The mean (and 95% confidence intervals) for total and for the categories of behaviours of weekend day sedentary time, for all adults and stratified by work status.

Age group	weighted n	Mean hours of total weekday sedentary time (95% confidence interval[a])	Mean hours of weekday TV/screen time (95% confidence interval[a])	Mean hours of week day other leisure sitting time (95% confidence interval[a])
Men				
16-24	973	6.2 (5.9, 6.5)	4.2 (3.9, 4.5)	2.0 (1.8, 2.1)
25-34	1093	5.7 (5.5, 6.0)	3.7 (3.5, 3.9)	2.0 (1.9, 2.1)
35-44	1089	5.5 (5.3, 5.7)	3.6 (3.4, 3.8)	1.9 (1.8, 2.0)
45-54	1277	5.7 (5.5, 5.9)	3.8 (3.6, 3.9)	2.0 (1.9, 2.1)
55-64	1060	6.2 (6.0, 6.4)	4.0 (3.9, 4.2)	2.1 (2.0, 2.2)
65-74	799	6.9 (6.7, 7.1)	4.3 (4.2, 4.5)	2.6 (2.5, 2.7)
75+	522	7.4 (7.2, 7.7)	4.2 (4.0, 4.5)	3.2 (3.0, 3.4)
Women				
16-24	953	5.8 (5.6, 6.1)	3.4 (3.2, 3.6)	2.4 (2.2, 2.6)
25-34	1147	5.3 (5.1, 5.4)	3.1 (3.0, 3.3)	2.1 (2.0, 2.2)
35-44	1162	5.2 (5.0, 5.3)	3.1 (3.0, 3.2)	2.0 (2.0, 2.1)
45-54	1348	5.5 (5.3, 5.6)	3.4 (3.2, 3.5)	2.1 (2.0, 2.2)
55-64	1111	5.8 (5.7, 6.0)	3.5 (3.4, 3.6)	2.3 (2.2, 2.4)
65-74	895	6.5 (6.3, 6.7)	3.9 (3.8, 4.0)	2.6 (2.5, 2.7)
75+	753	7.3 (7.1, 7.5)	4.2 (4.0, 4.3)	3.1 (3.0, 3.3)

[a]95% confidence intervals calculated using Taylor Series Linearisation method to account for complex survey design.

Relative contributions of the categories of behaviours of weekday sedentary time

Figure 4 shows the mean relative contributions of the categories of behaviours to weekday ST, stratified by work status (see Supplementary Tables 3 and 4 for 95% CIs and regression results). For those that worked (Figure 4A), the relative contribution of sitting time at work was highest for both sexes between the ages of 25 to 64 (35-45% (33-47%) compared to 33.6% (30-37%) for men and 31% (26-36%) for women aged 65-74 years; all $p<0.01$). For those aged 16 to 74 years, leisure TV/screen ST showed the converse relationship. The highest contributions were seen amongst 16-24 year olds (50% (47-54%) for men and 45% (42-47%) for women). Other leisure ST was relatively constant between the ages of 16-74, ranging between 19 and 30% (18-32%).

Amongst those not in work (Figure 4B), the lowest contribution of leisure TV/screen ST (57-58% (55-59%)) and the highest contribution of other leisure ST (42-43% (41-45%)) was evident in those over the age of 75 (p<0.001 compared to all other age groups). For men, there was a gradual decline with age of the relative contribution of leisure TV/screen ST, whilst for females there was some evidence of a peak in middle-age.

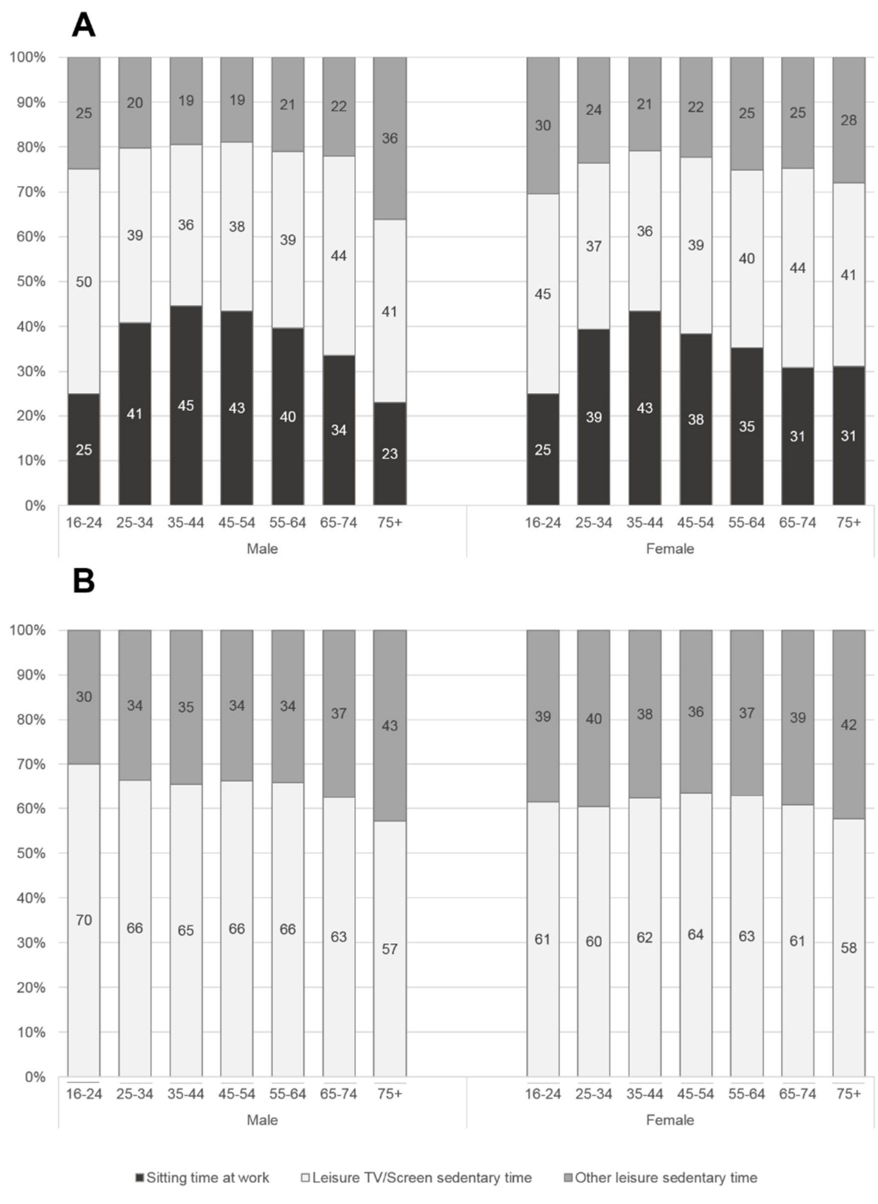

Figure 4. The relative contributions of the categories of behaviours to weekday sedentary time for adults in Scotland, by age group and sex, stratified by work status.
Figure 4 caption. A: Those in work in the four weeks prior to interview. B: Those not in work in the four weeks prior to interview.

Relative contributions of weekend day sedentary time

Figure 5 shows the mean relative contributions of the categories of behaviours of weekend day ST (see Supplementary Table 3 and 4 for 95% CIs and regression results). Men over 75 years spent the lowest proportion of their weekend day ST watching TV or other screens compared to all other age groups (56% (54-58%) compared to 61-65% (60-68%) for 16-74 year olds; all $p<0.001$). This trend was not apparent amongst women where the division between leisure TV/screen ST and other leisure ST was more consistent between the age groups (ranging between 56-60% (55-62%); interaction effects for age groups between 16-65 years all $p<0.05$). This interaction effect could also be interpreted as indicating lower relative contributions of leisure TV/screen ST to weekend day ST for women compared with men, except in the oldest two age groups.

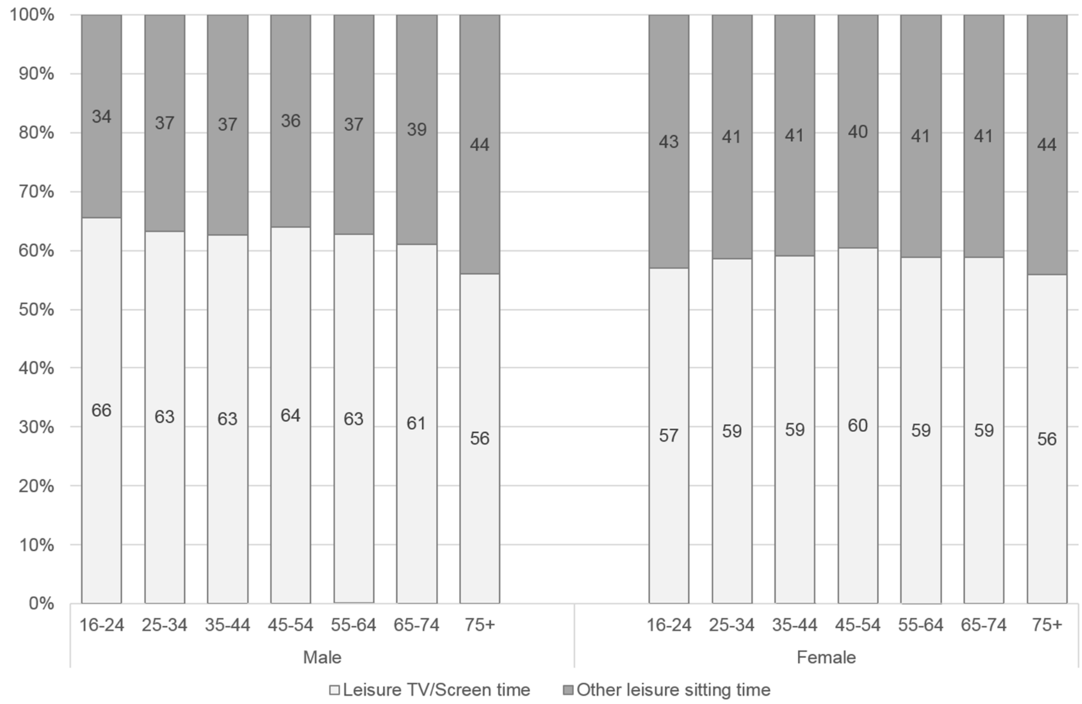

Figure 5. The relative contributions of the categories of behaviours to weekend day sedentary time for adults in Scotland, by age group and sex.

Discussion

The main finding from this paper is that including work ST in the estimates for weekday ST changes our understanding of how ST varies by age and sex for adults in Scotland. Without its inclusion, we see a j-shaped curve with the oldest age groups being most sedentary, and middle-aged adults the least. Our results indicate that this is only the case for women who do not work; all others demonstrate a different relationship between age group and weekday ST.

We have also found that, for those in work, up to 45% of weekday ST is accumulated at work. Leisure TV/screen ST made up over half of leisure ST for all age groups, both sexes, those in and out of employment, on weekdays and weekend days.

Weekday sedentary time including sitting time at work

The previous analyses of SHeS and HSE data have led to the assumption that older adults are the most sedentary age group within the UK (British Heart Foundation, 2014). Our results challenge that perception and stress the need to analyse the data on ST at work from UK national surveys. Without these analyses the potential health risk associated with ST is being underestimated for the working population. Our results also suggest that we need interventions to tackle high levels of ST in early and middle-age where patterns may develop, and that the workplace could be an appropriate place to target.

Our results are supported by some international multi-country studies that have also failed to show an increase in ST with age (Bauman et al., 2011; Bennie et al., 2013; Loyen, van der Ploeg, Bauman, Brug, & Lakerveld, 2016). This could be due to the method: all of these studies used a single item to ask about sitting time on a 'usual' day, although two of them specified weekday (Bauman et al., 2011; Bennie et al., 2013). Contrary to the present results, however, two of these reported the highest levels of ST amongst young adults (Bauman et al., 2011; Loyen, van der Ploeg, et al., 2016). It is possible that these mixed results could be explained by variations in the reference group. Our study chose to use the oldest age group, while others choose the youngest (Bennie et al., 2013), second youngest (Loyen, van der Ploeg, et al., 2016), or middle aged adults (Bauman et al., 2011). As this group drives all the comparisons, it is particularly important that this group have a sufficient sample size to enable differences to be detected, and are representative of their target population. In the present study, the older adult sample in the SHeS should be representative of those living in private households. However, this does not include those in medical or long-term care establishments who may be more sedentary than respondents to the survey (Bromley et al., 2015).

We also found that, amongst adults that do not work, the relationship between age group and reported weekday ST was different for men and women. We speculate that the difference between middle aged men and women could be due to different reasons for not being at work: women may be more likely to be involved in childcare, which may involve lower levels of ST, whilst men may be more likely to be unable to work for health reasons, which may result higher levels of ST. These speculations are tentatively supported by Eurostat data for the United Kingdom: in 2013, 5% of men compared to 29% of women stated their main reason for not seeking employment was "looking after children or incapacitated adults", while 31% of men and 18% of women gave "own illness or disability" as their answer (Eurostat, 2016). If this sex difference is confirmed in other datasets using other populations and other measurement methods, then further research should investigate the potential reasons for these differences.

In the present study, the average reported ST for men and women ranged between 6.6-7.8 hours on weekdays and 5.2-7.4 hours on weekend days for the different age groups. These figures are slightly higher than some estimates from international studies using self-report questionnaires. The 2013 Eurobarometer survey asked over 24,000 inhabitants (≥15 years) of EU member states a single-item question on sitting. The whole sample mean was 4.9 hours, and the Great Britain sub-sample mean was 5.0 hours (Milton, Gale, Stamatakis,

& Bauman, 2015). A recent review of population-level estimates for daily ST in European countries found the averages reported ranged between 2.5 hours/day to 10.3 hours/day, and UK studies had the largest variation of any nation (Loyen, Verloigne, et al., 2016). The large variation may be attributable to the variety of self-report and device-based measurement methods used, and the statistics reported (medians and means). These results strengthen the case for further work to find a common solution to measuring ST at a population-level (Dall et al., 2017). This will help us to fully understand the potential health-burden that it is placing on our society.

Behaviour-specific sedentary time

Our results show that for those that work, work ST makes up between one-quarter to nearly half of weekday ST. This justifies its inclusion in prevalence estimates. However, it is unclear why these proportions are lower than usual ranges reported in the literature (Clemes, O'Connell, & Edwardson, 2014; Clemes, Patel, Mahon, & Griffiths, 2014; Kazi, Duncan, Clemes, & Haslam, 2014; Ryan, Dall, Granat, & Grant, 2011), particularly, as described above, when the overall ST estimates are fractionally higher than other studies. We cannot rule out that that it is due to differences in measurement methods and/or contexts. The studies cited above use a variety of methods (objective, subjective, and a combination), and so it is possible that the context of data collection (e.g. in a wider health survey, or a specific study on sitting time at work) affected the reporting of domain-specific ST.

Like others, we found that leisure TV/screen ST was a greater contributor to leisure ST than other behaviours such as reading or eating (Clemes et al., 2015; Kazi et al., 2014). This applied to all adults, although was evident to the greatest extent amongst the 16-24 year olds. The cross-sectional nature of these data prevents us from making judgements as to whether this is a societal change that will continue as the current 16-24 year olds age, or whether it is a feature of that age group. It is nonetheless concerning given the potentially greater deleterious effects on health that TV viewing has compared to other sedentary behaviours (Ekelund et al., 2016).

We did not find substantial differences by sex in the relative contributions of the categories of behaviours. This is in contrast to the findings of Proper, Cerin, Brown, and Owen (2007). This may be due to the fact they looked at differences in individual activities rather than categories of behaviours in a sample of working-age Australian adults.

Implications for policy and practice

Based on these results, we would recommend that policy-makers in Scotland address the levels of ST amongst the adult population. The average weekday ST reported by the men and women in the different age groups ranged between 6.6 and 7.8 hours/day (95% CI 6.3-8.0). This implies that a large proportion of the population are at an increased risk of all-cause mortality, cardiovascular disease, type 2 diabetes, and some cancers amongst adults (Biswas et al., 2015; Chau et al., 2013; Pandey et al., 2016). A first step would be the addition of an appropriate indicator to the existing framework for monitoring physical activity levels in Scotland: the 'Active Scotland Outcomes Framework' (The Scottish Government, 2014).

Our results suggest that a key target group for intervention are early-to-middle aged adults who are in employment. They reported some of the highest weekday ST levels (group averages over 7 hours per day), close to half of which was accumulated at work. A recent review by Shrestha et al. (2016) found tentative evidence to suggest sit-to-stand desks could reduce work ST, at least in the short term. There was limited high quality evidence for other intervention types and so we support their call for more well-designed studies in this area. Regardless of sex or employment status, adults in Scotland accumulated more of their leisure ST through TV/screen time than other leisure-time sedentary behaviours. Wu, Sun, He, and Jiang (2016) found that interventions involving health promotion or counselling rather than automated monitoring of screen time were most effective. This suggests interventions could be targeted at reducing TV/screen time, however, national surveillance in Scotland should decide whether the current level of behaviour-specific detail is appropriate to inform such interventions.

The challenge for researchers and policy-makers together, is to interpret the constantly evolving evidence that currently implies an interaction between levels of physical activity and ST on health outcomes (Ekelund et al., 2015), into clear public health messages. It may be, as Buckley et al. (2015) suggest, that encouraging people to “simply get standing and moving more frequently” could be the “first behavioural step” towards a healthier lifestyle as it is potentially more achievable than the aerobic physical activity guidelines (Department of Health, 2011).

Strengths and limitations

This paper is the first to use nationally representative data to show the differences by age and sex in the reported ST amongst adults in Scotland. In England, the HSE uses the same questions and method for deriving estimates for ST as the SHeS (Craig & Mindell, 2013), and the levels of ST are similar between the nations (Scholes & Mindell, 2013). Therefore, one would expect similar results if one repeated this analyses on the HSE data.

There are some limitations to this study and it is important to consider what effect they may have on the interpretation of the results.

Firstly, the data are self-reported and are therefore prone to error (random and systematic) in the recall process (Atkin et al., 2012). Some but not all studies have found that self-reported methods often produce lower estimates of ST compared to objective measures (Healy et al., 2011). This would only strengthen the case for addressing the issue of high ST amongst adults in Scotland. However, it is important to remember that self-report is the only realistic method of measurement for population-level surveillance in Scotland at present, and has the benefit of providing behaviour-level information (Dall et al., 2017).

Secondly, participants may not report some ST because they are carrying out activities that are not explicitly prompted. For example, time spent in motorised transport is not explicitly mentioned in the questions, nor is time spent sitting at school or university. The latter may particularly affect the youngest age group and is a potential explanation for their lower levels of reported ST.

Conclusion

In this paper, we have shown that the relationship between weekday ST and age and sex differs from our current understanding when ST at work is included in the measure. Our results challenge the conventional understanding that older adults in Scotland report the highest levels of ST, as the majority of middle-aged adults reported similar levels to older adults. In light of these results, we suggest changing the way national prevalence estimates are calculated for Scotland and England, so that they include ST at work. We have also shown the division of ST in three categories of behaviours. Based on these results, we recommend that ST at work amongst early-to-middle aged adults and leisure TV/screen time for all adults are considered as targets for interventions to reduce ST.

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Abbreviations:

ST – Sedentary time

MET – Metabolic equivalent of task

TV- Television

SHeS – Scottish Health Survey

HSE – Health Survey for England

CI – Confidence interval

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Geolocation statement: This study was conducted in at the University of Edinburgh, Scotland, UK.

Supplementary online material: Supplementary File 1 contains the relevant items from the SHeS questionnaire, Supplementary File 2 is a summary of our unpublished analysis into the validity and reliability of these items, Supplementary Tables contains additional analysis output. The dataset analysed during the current study is available in the UK Data Archive repository, SN 7594 http://dx.doi.org/10.5255/UKDA-SN-7594-1.

8.4 Principal Findings

The four key findings of this paper are that for adults living in Scotland between 2012 and 2014 (1) the inclusion of ST at work changed our understanding of how total ST varied with age, (2) middle-aged adults in employment had comparable levels of total ST to those aged 75 years and over, (3) there were differences between the sexes in the age-related patterning of ST amongst those not in work, and (4) work made up 30-45% of total ST for those in work, with TV/screen time the greatest contributor to leisure-time ST.

8.5 Discussion of Main Themes

8.5.1 Total sedentary time and age

The published paper contains a brief discussion of other literature that did not find any increase in ST with age. The journal word count did not permit discussion of studies that found the opposite and the possible explanations.

Nationally representative data from both the U.S. and Canada have shown increases in total ST with increasing age, even when ST at work is measured (Colley et al., 2011; Matthews et al., 2008). It is unlikely that differences in the sample frame are the cause; these surveys, like the SHeS, do not include those in nursing homes who are likely to have high levels of ST and therefore could plausibly increase the average values in the older age groups. It is possible that there are true differences between nations, for example, North America has greater car use than European nations (Bassett, Pucher, Buehler, Thompson, & Crouter, 2008), although it is unclear whether this differs by age group. Or, it could be due to measurement differences: both North American surveys used objective measurement instruments compared to the self-report questionnaire in the SHeS. The U.S. National Health and Nutrition Examination Survey (NHANES) used the uni-axial ActiGraph 7164

(Matthews et al., 2008) while the Canadian Health Measures Survey used the tri-axial Actical (Colley et al., 2011). Both used a cut-point of <100 counts per minute to determine ST. It is possible that these devices differed from the SHeS self-report questionnaire in their ability to capture SBs for which participation rates varied by age. Or, there could have been differences in compliance rates that introduced bias. Alternatively, social desirability bias could have been evident/stronger in the older age group compared to the younger adults.

However, this implies, potentially wrongly, that the error is with the SHeS estimates. Objective measures themselves have their own limitations for measuring ST, particularly those used in the studies under discussion. A tri-axial is better than a uni-axial accelerometer at detecting the difference between standing and sitting time as it measures acceleration in more planes of movement, but neither are as accurate as inclinometers which also measure posture (Dowd, Harrington, Bourke, Nelson, & Donnelly, 2012; Grant, Ryan, Tigbe, & Granat, 2006). Healy, Clark, et al. (2011) summarised the validity and reliability evidence for the ActiGraph 7164 in relation to its use in population surveillance and warned that there was a wide range of error associated with the estimates. Other potential sources of error include reactivity, distinguishing ST from non-wear time, and decisions made in the processing and analysis phases (see Kang & Rowe, 2015, for more details). Therefore, it would be premature to suggest that Study 3's findings are incorrect. Chapter 9 contains further discussion over the validity and reliability of the SHeS for the surveillance of total ST.

8.5.2 Implications of work status

One of the most interesting findings of this paper was that the patterning of ST by age differed for men and women who were not in employment (39% of the weighted sample). This was not the case amongst those in employment. There is tentative support for this finding from NHANES data (measured by the uni-axial 7164;Kwak, Berrigan, van Domelen, Sjöström, & Hagströmer, 2016). They found that unemployed men recorded significantly more ST than employed men (519 (95% CI: 502-535) and 468 (95% CI: 461-475) minutes per day, respectively). Meanwhile, unemployed women recorded similar ST to employed women (465 (95% CI: 455-474) and 475 (95% CI: 468-482) minutes per day respectively). The authors speculated that this could be due to unemployed women undertaking light physical activity such as domestic chores. The results of Study 3 provide further insight as the differential pattern by age is evident. The fact that the largest differences were amongst the middle-age groups suggests that childcare could be an explanation. Capturing the PA undertaken by women, particularly those with young children, is a known issue (Ainsworth, 2000; Collins, Miller, & Marshall, 2007), so perhaps one should expect this group to report low levels of ST. Interestingly, interactions by age and work status were not evident in parallel analyses on nationally representative Swedish data (Kwak et al., 2016). Further research is needed before speculations over cultural differences can be supported.

8.5.3 Should a domain-focussed approach be advocated?

In Chapter 6, I highlighted the importance of understanding the context of MVPA behaviour for designing and resourcing behaviour change efforts appropriately. This is equally applicable to ST. There are many examples of domain- or behaviour-specific ST interventions (Shrestha et al., 2016; Wu, Sun, He, & Jiang, 2016). The results of this paper would support interventions amongst those in work to help reduce or break up their ST. However, the current evidence for workplace interventions is of low quality according to a recent Cochrane review (Shrestha et al., 2016). This was mainly because difficulties in concealing the randomisation in many trials could have introduced bias. It is important that high quality long-term evidence exists before national policies are developed because there is also evidence to suggest prolonged standing can have adverse health effects (P. Smith et al., 2017).

It is also important to consider the evidence for domain- or behaviour-specific health effects. It is not clear that occupational ST is itself harmful (van Uffelen et al., 2010). Recently, a Danish cohort study found no difference in mortality rates between those sitting for more or less than 24 hours per week at work (van der Ploeg, Møller, Hannerz, van der Beek, & Holtermann, 2015). There are two limitations of this study that should be noted: (1) total ST was not adjusted for, and (2) it may not have been possible to eliminate all confounding particularly relating to socio-economic position. This has parallels with the discussion of the potentially harmful health effects of occupational MVPA (Straker et al., 2017; see Section 6.5.3). It is clear that more research is needed to fully disentangle the effects of socio-economic position and movement behaviours at work. It is also important to understand how the total time spent in a posture interacts with the frequency of posture change with regards to health outcomes.

Given these uncertainties that are particularly pertinent to workplace ST, it may be wiser for policies focus on reducing TV viewing or screen time. Study 3 estimated that this made up more than half of all leisure-time ST for adults in Scotland, regardless of age, sex, or work status. As mentioned in Section 3.3.4, it is plausible that the strong associations between TV viewing and health may in part be driven by concurrent behaviours such as snacking (Jeffery & French, 1998; Meyer et al., 2008). Others have suggested that compared to other behaviours, TV viewing may be associated with fewer breaks (DiPietro, Jin, Talegawkar, & Matthews, 2017).

Although these factors may confound the health effects directly attributable to the sedentariness of TV viewing, they only strengthen the case for changing the behaviour. Emerging research from the ‘Seniors – Understanding Sedentary Patterns (USP)’ study suggests that TV viewing can be further divided into ‘purposeful’ and ‘vacant’ (Dr Claire Fitzsimons, personal communication). This distinction may be important as it would determine whether an intervention should try to target a change in posture or replacing the behaviour.

8.6 Implications for Policy

Figure 13 shows how Study 3 has contributed to Scottish policy and how it may continue to do so (for further details see Appendix 20). Study 3 has also been influential for future surveillance in Scotland. This is discussed in Chapter 9 as the results of Study 4 were also relevant to that impact story.

The most important contribution is the potential inclusion of a ST indicator on the ASOF. The process through which this occurred has been described in Section 7.8. Although Study 3’s results were not published at the time, the analysis had been completed and so I was able to incorporate this knowledge into the proposal (see Appendix 17).

There was one major difference between the MSA and BCA indicators and that proposed for ST: there was no quantified recommendation for total ST that could be easily converted into an ASOF indicator. The current 19 indicators on the ASOF are all proportions of the population (or a sub-group) undertaking a relevant activity (The Scottish Government, 2014a). Reporting the mean ST for adults would not fit with this, nor would it be a helpful measure of whether improvements were being made. Some ST, unlike smoking, may not be harmful, but may even be necessary for good health (Wijndaele & Healy, 2016). Prolonged standing has also been associated with negative health outcomes (Coenen et al., 2016; P. Smith et al., 2017), so a reduction in the population mean value may not actually reflect an improvement in population health.

Therefore, an indicator that monitors the proportion of adults in Scotland at risk from high levels of total ST would be preferable. The question was: what should the threshold value be? (The SB and Obesity Expert Working Group, 2010) concluded there was 'insufficient evidence to agree a quantified recommendation for reducing ST amongst adults' when advising on the 2011 U.K. CMOs' PA guideline update. Since then, there have been two meta-analyses suggesting a non-linear relationship exists between ST and the risk of ACM and morbidity (Chau et al., 2013; Pandey et al., 2016). Chau et al. (2013) showed each hour of ST was associated with a 2% increase in risk of ACM (after PA was taken into account), up to 7 hours. Above this threshold, each additional hour of sitting was associated with a 5% risk of ACM. Similarly, Pandey et al. (2016) showed that above a threshold of 10 hours sitting per day, CVD risk increased at a greater rate than below it.

Still, experts are cautious to precisely quantify a threshold that might be interpreted as a recommendation (van der Ploeg & Hillsdon, 2017). There is an awareness that substantial changes to public guidelines can generate mistrust and loss of credibility of the field (Carpenter et al., 2016; Nagler, Fowler, & Gollust, 2015). The continual debate around saturated fats and their link to heart disease is an example of this (Dehghan et al., 2017). Already, a group of academic experts have argued against calls for guidelines on screen time for children in an open letter to The Guardian (The Guardian, 2016, 2017). They argued that without robust, high quality evidence, this risked introducing 'unnecessary, ineffective, or even potentially harmful policies'. Similarly, a leading SB researcher Dr Travis Saunders wrote a blog post after the release of workplace ST guidance (Buckley et al., 2015;

PLOS|blogs, 2015). In it, he expressed his surprise that these were being produced so early, even if he broadly supported their conclusions. He also noted the potential effect on future research: that analyses would cluster around the thresholds suggested in the guidance rather than looking across the full range which may be preferable at this stage in building the evidence base.

This situation made it difficult to strike an appropriate balance when communicating with policy-makers. I wanted to maximise the opportunity to increase the profile of SB on the national policy agenda, yet ensure all advice was fully supported by the current evidence. This was not a unique position for an academic researcher to be in: one of the common tensions between policy-makers and academic researchers is the level of evidence that each group consider adequate for decision making (Cairney & Oliver, 2017). To ensure I was making appropriate judgements, I consulted my PhD Steering Group and supervisors for advice. I also shared the proposal for the ASOF indicator with leading academics from Glasgow Caledonian University. This was important to ensure that all the academics likely to be communicating with the Scottish Government on this topic were in broad agreement as contradictory academic evidence is a known barrier to its use by policy-makers (Andermann, Pang, Newton, Davis, & Panisset, 2016).

It is likely that a quantified recommendation for total ST will be developed in the near future, or at least be combined within 24-hour movement guidelines (Chaput, Carson, Gray, & Tremblay, 2014). I have identified six aspects of the relationship between total ST and health that require more evidence before this is likely to occur: (1) greater understanding of the dose-response relationship to determine whether thresholds could appropriately represent safe and harmful levels of ST, (2) precision around a potential threshold level, (3) how MVPA modifies the relationship between total ST and health, (4) an understanding of how interruptions in ST may affect this, (4) whether all excess SBs are equally harmful, (5) what alternative behaviours should be recommended to replace ST, and (6) whether the recommendation should be different for different age groups.

Figure 13 also shows how Study 3 has been used by academics at the Glasgow Caledonian University in a project to collate advice for those designing interventions to reduce ST. I was contacted about the project (Seniors-USP) after I gave a series of presentations on the findings of Study 3. Although not specifically addressing the aim of informing national policy, the project may ultimately influence how national policies are implemented.

It is interesting to reflect that some of the opportunities to discuss the findings of Study 3 (and wider evidence relating to SB and health) occurred as a result of work relating to Studies 1 and 2 (see Figure 13). It is yet another example of how complex the interactions can be between academic research and policy (see Section 5.2). It is important to be aware of this so that the utility of opportunities to inform policy can be maximised.

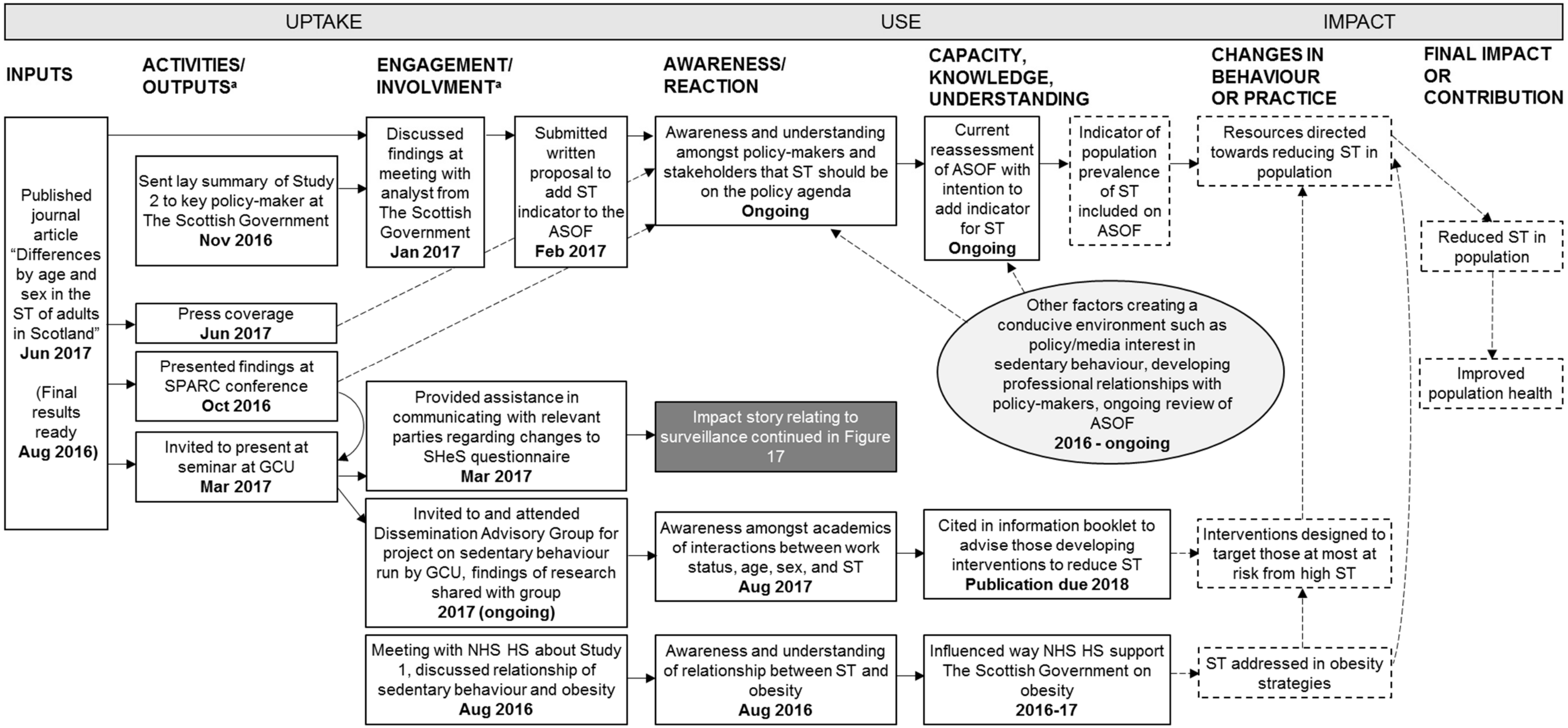

Figure 13. Tracing the Impact of Study 3.

Based on the Pathway for Impact from Morton (2015). Continuous arrows represent connections that evidence supports (see Appendix 20); dashed lines represent plausible connections. [a]Activities/Outputs covers broad knowledge exchange activities, Engagement/Involvement covers user interactions. ASOF = Active Scotland Outcomes Framework; GCU = Glasgow Caledonian University; NHS HS = National Health Service Health Scotland; SHeS = Scottish Health Survey; SPARC = Scottish Physical Activity Research Connections; ST = sedentary time.

8.7 Strengths and Limitations

As with the previous two chapters, many of the strengths and weaknesses of the work were discussed in the published article. Table 6 summarised how the limitations of previously published figures have been addressed in the present study. Many of the learning points from Study 1 that were addressed in Study 2 (e.g. combining survey years to increase sample size, and focussing on the trends rather than the *p* values) were also addressed in Study 3.

One issue Study 2 highlighted was the need to explain interaction effects clearly. I addressed this by providing explanations in the published article. My experience of discussing the papers findings with journalists demonstrated to me that there was still a high potential for misinterpretation. This made me aware of the need to collaborate closely with those writing the press release to minimise this risk.

A key strength was that I was able to consider the findings of Study 4 (an assessment of the evidence for the validity and reliability properties of the SHeS measurement method) when interpreting the results of the present work. Study 4 concluded that the SHeS questionnaire is better suited to ranking individuals as opposed to quantifying their total ST. This was incorporated into Study 3 so that main findings of this paper referred to relative comparisons between sub-groups.

One could criticise this work for not taking into account concurrent MVPA levels. As was briefly described in Section 8.1 and will be covered in greater detail in Section 11.1, high levels of MVPA may attenuate or even eliminate the detrimental health effects of SB. Study 1 showed that MVPA levels vary by age and gender and therefore a combined analysis could have allowed for more nuanced policy recommendations. MVPA was not included in the present descriptive analysis for three reasons. Firstly, as this was a cross-sectional study, it would have required an assumption about what levels of MVPA were sufficient to eliminate the effects of high ST, as it is still not clear how much is sufficient. Secondly, it would have required the categorisation of total ST. There was a risk that, if included in this paper on the descriptive epidemiology of the ST of adults in Scotland, it would have been interpreted as a recommendation. As discussed in Section 8.6, this was still a debated issue. Thirdly, the sample size was not sufficient to consider a third covariate whilst still providing appropriate levels of certainty to the estimates. Instead, I decided to investigate the joint effects of MVPA and total ST on health outcomes in Study 5. The ways in which it overcomes these limitations are discussed in Section 10.2.

8.8 Chapter Summary

This work has shown that including ST at work in estimates of the total ST of adults in Scotland changes our understanding of how it varies by age, sex, and work status. The results showed that middle-aged adults in work report sitting for as long as adults over 75 years and this is important for considering intervention targets and design. The work has been influential in proposals to include an indicator of ST on the ASOF, although this did require some difficult judgement calls regarding the interpretation of current research.

Chapter 9: Study 4 – Does the Scottish Health Survey Produce Valid and Reliable Estimates for Physical Activity and Sedentary Time: A Review of the Evidence

Study 4 reviews the available evidence relating to whether the 2012-15 SHeS method for estimating PA and ST produces valid and reliable results. This is assessed in relation to the results of Studies 1-3.

This work has not been published and so is presented in the form of an extended manuscript. The work in this thesis is an extension of a project funded by a Seedcorn grant from Moray House School of Education at the University of Edinburgh. Dr Graham Baker was the Principal Investigator on the grant; Dr Paul Kelly and I were co-investigators. A final report of the Seedcorn-funded project is included in Appendix 21. I led the work for both the Seedcorn-funded project and the work in this thesis, undertook the evidence reviews, and wrote both the funded project final report and this chapter. Dr Graham Baker and Dr Paul Kelly acted in a supervisory role for the Seedcorn-funded project, Dr Paul Kelly and Dr Claire Fitzsimons acted in a supervisory role for the work in this thesis.

9.1 The Edinburgh Framework

The concepts of validity and reliability underpin all research findings. They affect how we interpret and apply them. P. Kelly et al. (2016) developed the EF as a hierarchical way of considering the sub-components of validity and reliability to help researchers considering whether a measurement method is appropriate for the intended purpose (see Figure 4 in Section 2.11). There are parallels with other frameworks designed to help researchers choose an appropriate PA measurement method in that the need to consider the purpose is stressed (Gabriel, Morrow, &

Woolsey, 2012; Mokkink et al., 2010; Sternfeld & Goldman-Rosas, 2012; Troiano, Gabriel, Welk, Owen, & Sternfeld, 2012).

Another aim of the EF was to encourage researchers to convey this information to readers (P. Kelly et al., 2016). Readers are too often provided with insufficient information to be able to understand whether results are valid and/or reliable. For example, one study analysing the 2008 HSE MVPA data stated:

> The criterion validity of the PA questionnaire has been demonstrated in a study of 106 English adults from the general population (45 men) where the output of accelerometers (worn for 2 non-consecutive weeks over a month) was compared with the above questions. (Stamatakis, Hamer, Tilling, & Lawlor, 2012, p. 1330)

This sentence does not help the reader interpret the results of the study in a meaningful way. There are no indications as to how these conclusions were reached, the strength of the relationship, or the certainty associated with the findings.

This quote is also an example of another issue P. Kelly et al. (2016) sought to address: the false hierarchy where all devices are considered ‘more valid’ than all self-report instruments for measuring MVPA or ST. The use of terms ‘objective’ and ‘subjective’ measurements only perpetuate this inferred superiority (Fulton et al., 2016). Devices are not a criterion method if, for example, one is measuring compliance with the MVPA recommendation. Using accelerometry, which is based on a complementary but not interchangeable set of behavioural metrics, would be inappropriate as the data that the recommendation was based on was derived from self-report methods (see Chapter 3; Troiano, McClain, Brychta, & Chen, 2014).

9.2 Rationale for Study

As described in Section 4.4.5, there has been no direct assessment of whether the 2012-15 SHeS method for estimating PA and/or ST was appropriate for use in Studies 1-3. There was, however, evidence from related surveys such as the HSE or the Allied Dunbar National Fitness Survey (ADNFS; Scholes et al., 2016; Scholes et al., 2014). There was also information in the SHeS Technical Reports that was relevant to certain validity and reliability sub-components (Campbell-Jack & Hinchliffe, 2016). It was important to address the issue of validity and reliability so that I could appropriately interpret the results of Studies 1-3, and because such work had the potential to inform future surveillance in Scotland. The case for this only strengthened as I identified several concerns as I undertook the Studies 1 and 2 (e.g. the measurement of occupational MVPA or the content validity of the MSA and BCA summary measures).

As described in Section 5.1, I decided to undertake a review of the existing evidence rather than a direct assessment for three reasons: (1) understanding what evidence existed was an important first step, (2) there was not the time or resource to undertake a direct assessment in addition to the other secondary analysis work, (3) the future surveillance plans for the SHeS were unclear and so it was important to undertake work that was likely to be useful in all scenarios. The specific research questions for the present study were therefore: what evidence exists to support the use of the 2012-15 SHeS for the estimation of

1. (a) total and domain-specific minutes of MVPA, and (b) compliance with the MVPA recommendation,
2. compliance with the (a) MSA recommendation, and (b) BCA recommendation,
3. total daily ST.

Prior to this study, the EF's use had been theoretical; there were no published examples of it being used to guide instrument selection or to evaluate whether a prior decision was appropriate. However, compared to the two other frameworks that could potentially have been used to guide this review of evidence (Mokkink et al., 2010; Sternfeld & Goldman-Rosas, 2012), the EF was the only one that could consider the whole method rather than just the measurement instrument. Whether or not the results of Studies 1-3 were nationally representative was of critical importance given their aim of informing policy. Therefore, having a framework that considered factors such as the sampling methods was important.

The work presented in this thesis extended from the Seedcorn-funded project (see p.139). The focus of the Seedcorn-funded project was on the suitability of the EF for this purpose. This differs from the aim of the work presented in this chapter which focusses on the findings of evidence reviews. (The Seedcorn-funded project also only covered the evidence review relating to MVPA measurement in the SHeS). I used the findings from the Seedcorn-funded project to modify the EF for the present work in three ways: (1) I introduced a definition for the term construct validity, (2) I removed the sub-component inter-/intra-measure validity, and (3) I combined the sub-components of face and content validity.

Regarding (1), I used the definition of construct validity from Tudor-Locke, Williams, Reis, and Pluto (2004): the extent to which the measurement corresponds with other measures of theoretically-related parameters. P. Kelly et al. (2016) were aware this concept was missing from their 'version 1' of the EF, noting that it did not include 'nomological validity'. This is a similar concept relating to systems where changing one element will directly alter another (Liu, Li, & Zhu, 2012).

I removed the component of inter-/intra-measure reliability because the concept was covered by test-retest reliability. The combination of face and content validity was necessary for clarity of presentation of the results. As P. Kelly et al. (2016) explained, the theoretical methods for assessing these sub-components were similar. In practice, I found it hard to make a distinction between evidence relating to the two sub-components.

9.3 Methods

Evidence was identified through a non-systematic “snowballing” literature search carried out between January and March 2016, updated in October 2017. This was the most appropriate search strategy as much of the evidence was from governmental reports that were not indexed on academic search engines. Authors were contacted if the reports not publically available. Evidence relating to the ADNFS and the HSE were also considered as the 2012-15 SHeS originated from these surveys (see Appendix 22 for comparisons of relevant measurement instruments). Research concerning broader measurement issues was also considered.

Evidence was summarised under relevant sub-components of validity and reliability in the modified EF described in Sections 2.11 and 9.2 (P. Kelly et al., 2016). Each piece of evidence was rated according to whether it was supportive of the method’s intended use. The rating system was devised with awareness of the Cochrane scale for assessing risk of bias of studies in systematic reviews (Higgins & Green, 2011; see Table 7). The rating also factored in elements of study quality with particular reference to the ‘Hagströmer-Bowles Physical Activity/Sedentary Behaviour Questionnaire Checklist’ (Hagströmer, Ainsworth, Kwak, & Bowles, 2012). These ratings were checked by Dr Paul Kelly and Dr Claire Fitzsimons, any discrepancies were discussed and an agreement was reached.

Table 7. Ratings of Support for the Validity and Reliability Evidence

Supportive	There was strong and/or robust evidence to support the purpose
Weak supportive	There was some evidence to support the purpose but it was either weak and/or had relevant limitations.
Unclear	The evidence was unclear as to whether the purpose was supported or not.
Unsupportive	The evidence did not support the purpose.

9.4 Results

9.4.1 Total and domain-specific minutes of moderate-to-vigorous physical activity and compliance with the recommendation

This section and Figure 14 summarise the evidence relating to research questions 1(a) and (b). Although one of the principles of the EF is to distinguish between the purposes (a) and (b), in this case, the overlap of evidence was too great to justify presenting it separately.

A 'supportive' rating was given to internal validity because there was very limited missing data in the relevant variables for the MVPA summary measures (Strain, Fitzsimons, Foster, et al., 2016). Also, there was evidence that the 28-day time frame was chosen considering recall accuracy when designing the original ADNFS survey (Fentem et al., 1994). However, there do not appear to have been any investigations into the potential for social desirability bias, so this aspect remains unclear.

A 'supportive' rating was also given to external validity because the SHeS uses the best available methods to generate nationally representative results. For example, the sample frame used is the Postcode Address File which has been shown to cover all but 1.7% of population in Scotland (Gorman et al., 2014). However, it only covers those in private households (i.e. excluding the homeless, those in prison, and those in medical and long-term care establishments). This caveat may be particularly relevant to the oldest age-groups, given that health status is likely to be associated with care home residency. The 2012-15 SHeS Technical Reports do make this clear (Corbett et al., 2013, Corbett et al., 2014, Bromley, Campbell-Jack, and Hinchliffe, 2015, Campbell-Jack and Hinchliffe, 2016). The response rates for the 2012-15 SHeS were between 52-56% (see the Technical Reports); the Office for National Statistics considers response rates above 50% acceptable for producing good quality estimates (Office for National Statistics, 2014). The method for deriving the weighting variable used to adjust for known biases in non-response is detailed in the Technical Reports.

The rating for construct validity was different for different domains. There was strong 'supportive' evidence for inverse associations between total leisure-time MVPA and risk of ACM, CVD and cancer mortality regardless of frequency of participation (O'Donovan et al., 2017). Analysis of the 2003 SHeS also showed that higher levels of total weekly leisure-time MVPA were associated with reduced risk of obesity (Stamatakis, Hirani, et al., 2009). However, other analyses have questioned the associations between domestic activity and health outcomes, resulting in an 'unclear' rating for this domain. For example, more consistent associations have been demonstrated between MVPA levels and ACM and CVD event incidence when domestic MVPA was excluded from the leisure-time summary measure (Stamatakis, Hamer, et al., 2009). Also, no association was found between regular participation in domestic activity was not associated with a favourable CVD risk factor profile, but was for walking and sport and exercise participation (Stamatakis, Hillsdon, and Primatesta, 2007).

The face and content validity ratings were also split by domain. A number of studies questioned the method of allocating time spent in occupational MVPA (Joint Health Surveys Unit et al., 2007; Strain, Fitzsimons, Foster, et al., 2016), leading to an 'unsupportive' rating for this domain. The 2008 HSE added new questions to resolve the issues (R. Craig, Mindell, and Hirani, 2009), but the SHeS remained unchanged. Regarding the other domains, a report on the 2006 HSE raised some issues with specific sport and exercise activities. For example, there was ambiguity as to whether swimming included ‘splashing around’ as well as ‘doing lengths’, and ‘workout at gym’ covered too many activities for the intensity to be determined accurately (Joint Health Surveys Unit et al., 2007). Again, the 2008 HSE introduced additional questions to resolve these issues (R. Craig, Mindell, and Hirani, 2009), whilst the SHeS did not. However, one could argue that the SHeS questions on the relative intensity of these activities mitigate the concerns to some degree.

A ‘weak supportive’ rating was given to convergent validity as there was evidence of fair correlations between the MVPA estimates derived from versions of the HSE and uni-axial accelerometry or the short-form IPAQ (Joint Health Surveys Unit, 2007, Scholes et al., 2014, Scholes et al., 2016). In a comparison of the 2006 HSE and the uni-axial ActiGraph GT1M (n=61), the proportion meeting the 5x30 recommendation was derived from each method (33% for the 2006 HSE and 25% for the ActiGraph; Joint Health Surveys Unit, 2007). The Kappa statistic of 0.165 indicated ‘slight’ agreement although it was statistically non-significant. The intra-class correlation coefficient for the total weekly mean minutes of MVPA was 0.139 (statistically non-significant). No mean values were reported.

In a comparison of the 2008 HSE and the uni-axial ActiGraph GT1M (n=71), the proportion meeting the 5x30 recommendation was derived from each method (68% for the 2008 HSE and 49% for the ActiGraph; Joint Health Surveys Unit, 2007). The Kappa statistic of 0.264 indicated ‘fair’ agreement, and was statistically significant. The mean weekly minutes of MVPA derived from the 2008 HSE were 671 (standard deviation (sd)=744) minutes/week for men and 268 (sd=526) minutes/week for women. The respective figures from the ActiGraph were 333 minutes/week and 198 minutes/week (no measures of variance provided). The intra-class correlation coefficients were 0.45 and 0.42 for men and women respectively.

In a comparison of the 2008 HSE and the uni-axial ActiGraph (n=2175), the proportion meeting the 5x30 recommendation was derived from each method (60% for men and 54% for women from the 2008 HSE, and 60% for men and 45% for women from the ActiGraph; Scholes et al., 2014). The Kappa statistics from Wilcoxon signed rank tests were 0.32 (95% CI: 0.26-0.39) for men and 0.27 (95% CI: 0.22-0.33) for women, indicating fair agreement. The median daily minutes of MVPA derived from the 2008 HSE were 13.2 (Interquartile range (IQR)=41.7) minutes/day for men and 8.6 (IQR=31.4) minutes/day for women. The respective estimates from the ActiGraph were 26.9 (IQR=34.1) minutes/day and 18.8 (IQR=25.0) minutes/day. The Spearman's rho statistics from rank-order correlation tests were 0.38 (0.32-0.45) and 0.42 (0.36-0.48) respectively, indicating moderate levels of agreement. Agreement on all measures was lower when a 10-minute minimum bout length was applied to the ActiGraph data.

In a comparison of the 2012 HSE and the short-form IPAQ (n=1252), the proportion meeting the 150 mins recommendation were derived from each method. Across different age, gender, income, and health status sub-groups, the IPAQ estimates were 9.6-18.9 percentage points higher than those of the 2012 HSE (Scholes et al., 2016). No exact proportions were given except that 63.3% of the whole sample met recommendation when derived from the 2012 HSE. The prevalence-adjusted and bias-adjusted kappa (PABAK) statistic was 0.42 for all adults and ranged between 0.32-0.49 for the sub-groups (very few of the 95% CIs crossed zero), indicating fair to moderate agreement. The mean weekly minutes derived from each method were not reported but the Pearson's correlation coefficients were 0.43 for men and 0.40 for women.

However, there were considerable limitations that were common to all of the described studies. They included (i) the limitations of uni-axial accelerometers to infer total volume of MVPA (see Chen & Bassett, 2005 for discussion of this issue), (ii) non-overlapping measurement periods, (iii) incomplete reporting of results, and (iv) relatively small sample sizes in most cases.

There was no evidence relating to the criterion validity or the test-retest reliability. Regarding inter-/intra-rater reliability, the Technical Reports described procedures undertaken to promote inter- and intra-interviewer consistency (e.g. Corbett et al., 2013), leading to a 'supportive' rating. These included: production of a comprehensive script and instructions including prompts, regular supervision on interviews, and regular training days.

Behavioural stability was given a 'supportive' rating indicating that the 28-day recall period was suitable for capturing habitual behaviour over that period. The original ADNFS had piloted the questionnaire and established the reported hours of PA in each domain were relatively stable between assessments four weeks apart (Fentem et al., 1994). Two versions of the HSE have also been tested at an approximate four-week interval, and fair to moderate levels of agreement were found (Joint Health Surveys Unit et al., 2007). Respondents (n=61) were interviewed using the 2006 HSE approximately four weeks apart. The proportion meeting the 5x30 recommendation was 46% for the first interview and 29% for the second. The Kappa statistic was 0.378, which was statistically significant, indicating fair agreement. The mean weekly minutes of MVPA were 566 (sd=708) minutes/week and 689 (sd=847) minutes/week for men on the first and second interviews respectively. The respective figures for women were 421 (sd=592) minutes/week and 243 (sd=394) minutes/week. The intra-class correlation coefficients were 0.80 for men and 0.36 for women. In another study, respondents (n=71) were interviewed using the 2008 HSE questionnaire approximately four weeks apart (Joint Health Surveys Unit et al., 2007). The proportion meeting the 5x30 recommendation was 65% for the first interview and 46% for the second. The Kappa statistic was 0.55, which was statistically significant, indicating moderate agreement. The mean weekly minutes of MVPA were 627 (sd=846) minutes/week and 671 (sd=745) minutes/week for men on the first and second interviews respectively. The respective figures for women were 440 (sd=639) minutes/week and 268 (sd=526) minutes/week. The intra-class correlation coefficients were 0.89 and 0.76 respectively. Lastly, the interviews in the 2012-15 SHeS were spread out over the year which minimised seasonality effects over the whole sample (Corbett et al., 2013).

9.4.2 Compliance with the muscle strengthening and balance and co-ordination recommendations

This section and Figure 15 summarise the evidence relating to research questions 2 (a) and (b). Again, the overlap of evidence for (a) and (b) was substantial and so it was presented together.

The internal and external validity ratings were both ‘supportive’ for the same reasons explained above for research question 1(a) and (b): there was limited missing data (Strain, Fitzsimons, Kelly, et al., 2016), the choice of time-frame had considered recall accuracy (Fentem et al., 1994), and the estimates were nationally representative of those living in private households in Scotland after weighting.

There was no evidence regarding the construct validity of the measure, but the face and content validity were rated as ‘unsupportive’. Although expert advice had been sought to help classify the sport and exercise activities as MSAs and BCAs (Corbett et al., 2013), only activities in this domain are included. This leads to a discrepancy between the MSAs and BCAs included in the SHeS summary measure and those given as examples in the U.K. PA guidelines (Department of Health, 2011). For example, heavy gardening is recommended as a MSA but it is not included by the SHeS summary measure.

There was no evidence regarding the convergent, criterion, or test-retest reliability. For similar reasons to those described for research questions 1(a) and (b), inter-/intra-rater reliability was given a ‘supportive’ rating because of the procedures undertaken to promote inter- and intra-interviewer consistency (e.g. Corbett et al., 2013). Behavioural stability was rated as 'weak supportive' because the evidence described in the previous section indicated that MVPA behaviour was stable over a four week period (Fentem et al., 1994, Joint Health Surveys Unit, 2007), but there was no specific evidence for MSAs and BCAs.

9.4.3 Total daily sedentary time

This section and Figure 16 summarise the evidence relating to research question 3. Internal validity was given a 'weak supportive' rating: missing data was not a concern (Strain et al., 2017), however, there is evidence that ST questionnaires with an unanchored recall period (i.e. average day) produce larger underestimates of ST than those with fixed recall periods (Dall et al., 2017). The evidence for the 'supportive' rating for external validity is the same as that described in Section 9.4.1.

Construct validity was rated as 'weak supportive' as, although associations between the domain of TV/screen time and the risk of ACM and CVD had been shown (Stamatakis et al., 2011), total ST had not been investigated.

Face and content validity were rated as 'weak supportive' as the questions had undergone cognitive testing as part of their inclusion in the HSE (Joint Health Surveys Unit, 2007). However, my work in Study 3 led me to raise concerns about the lack of prompting for motorised transport and higher education (Strain et al., 2017). The latter may disproportionately affect younger adults.

The convergent validity evidence was rated as 'weak supportive', as there was evidence of fair levels of correlation between the measures of daily ST derived from the questionnaire and accelerometer-derived or the short-form IPAQ (Scholes et al., 2014, Scholes et al., 2016). For example, in a comparison of the 2008 HSE and the uni-axial ActiGraph GT1M (n=2175), the median minutes of daily ST was derived from each method 415.7 (IQR=207.5) minutes/day for men and 364.3 (IQR=197.1) minutes/day for women from the 2008 HSE, and 537.8 (IQR=137.5) for men and 509.3 (112.4) for women from accelerometry using 100 counts/min cut off (Scholes et al., 2014). The Spearman's rho statistics from rank-order correlation tests were 0.25 (95% CI: 0.19-0.30) for men and 0.30 (95% CI: 0.25-0.35) for women, indicating 'fair' levels of agreement.

Another study compared the 2012 HSE and the short-form IPAQ (n=1252). The total weekly minutes of ST were derived from each method (Scholes et al., 2016), although the 2012 HSE derived leisure-time ST only. No average values were given but the Pearson's correlation coefficients were 0.232 for men and 0.290 for women, indicating 'fair' levels of agreement. The proportion sitting for >9 hours/day was also derived from each method. The exact proportions were not given but the PABAK statistic was 0.60 for all adults and ranged between 0.49-0.75 for age, gender, income, and health status sub-groups. This indicated 'moderate' to 'substantial' levels of agreement.

However, limitations applied to the studies. These included: (i) the use of uni-axial accelerometers to infer total volume of ST (see Section 8.5.1 as to why these are not appropriate), (ii) non-overlapping measurement periods, and (iii) incomplete reporting of results.

There was no evidence relating to the criterion or test-retest validity. As previously, the steps taken to promote inter- and intra-interviewer consistency (Corbett et al., 2013) led to a 'supportive' rating for inter-/intra-rater reliability. Behavioural stability was rated as unclear because there are some suggestions that daily variations 9up to 4.5 hours/day across a seven-day period) in ST would make an unanchored recall period inappropriate (Barreira et al., 2016).

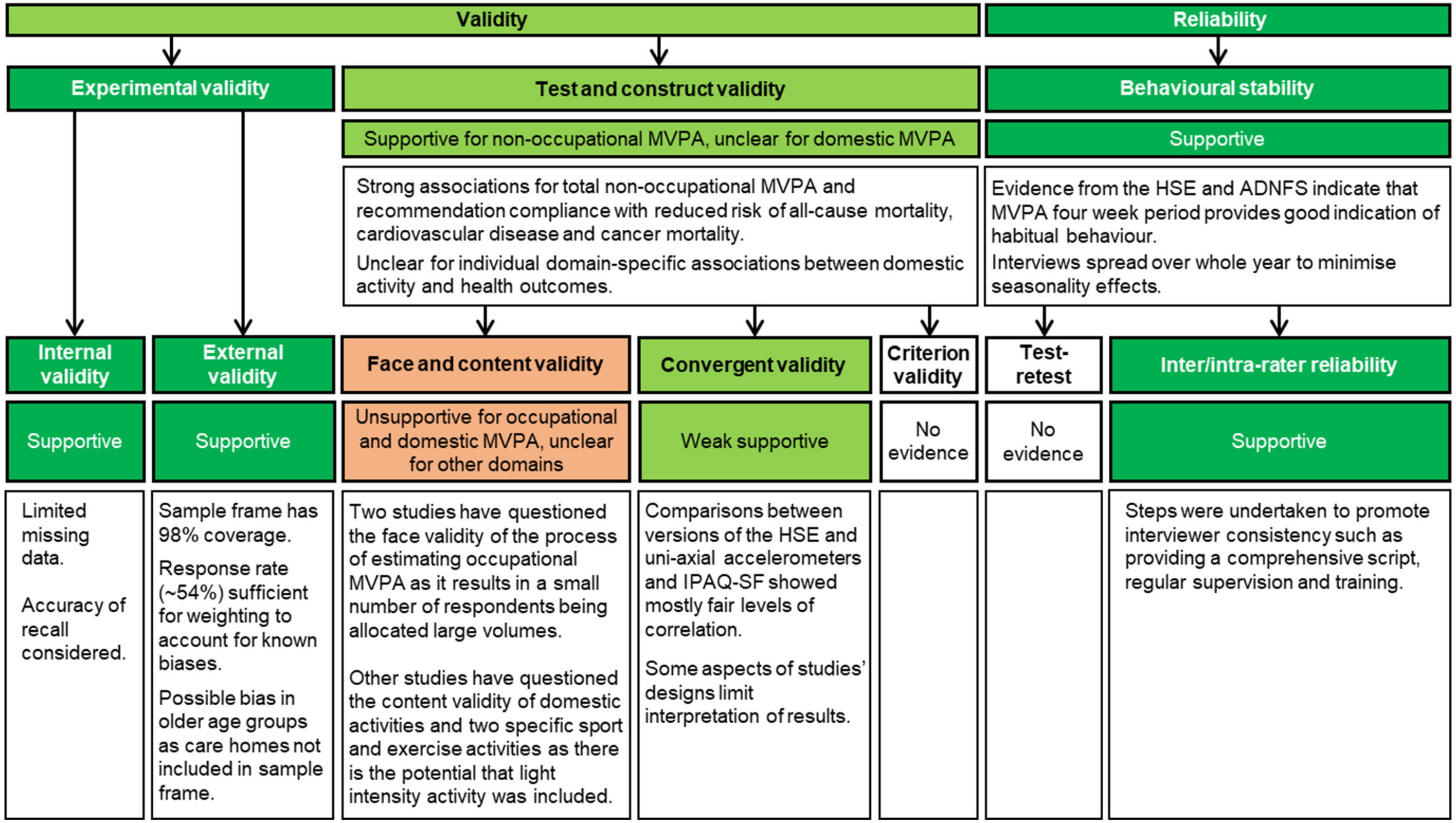

Figure 14. Summary of Validity and Reliability Evidence Concerning the Measurement of Moderate-to-vigorous Physical Activity by the 2012-15 Scottish Health Survey.

ADNFS = Allied Dunbar National Fitness Survey; HSE = Health Survey for England; IPAQ-SF = International Physical Activity Questionnaire Short-Form; MVPA = moderate-to-vigorous physical activity.

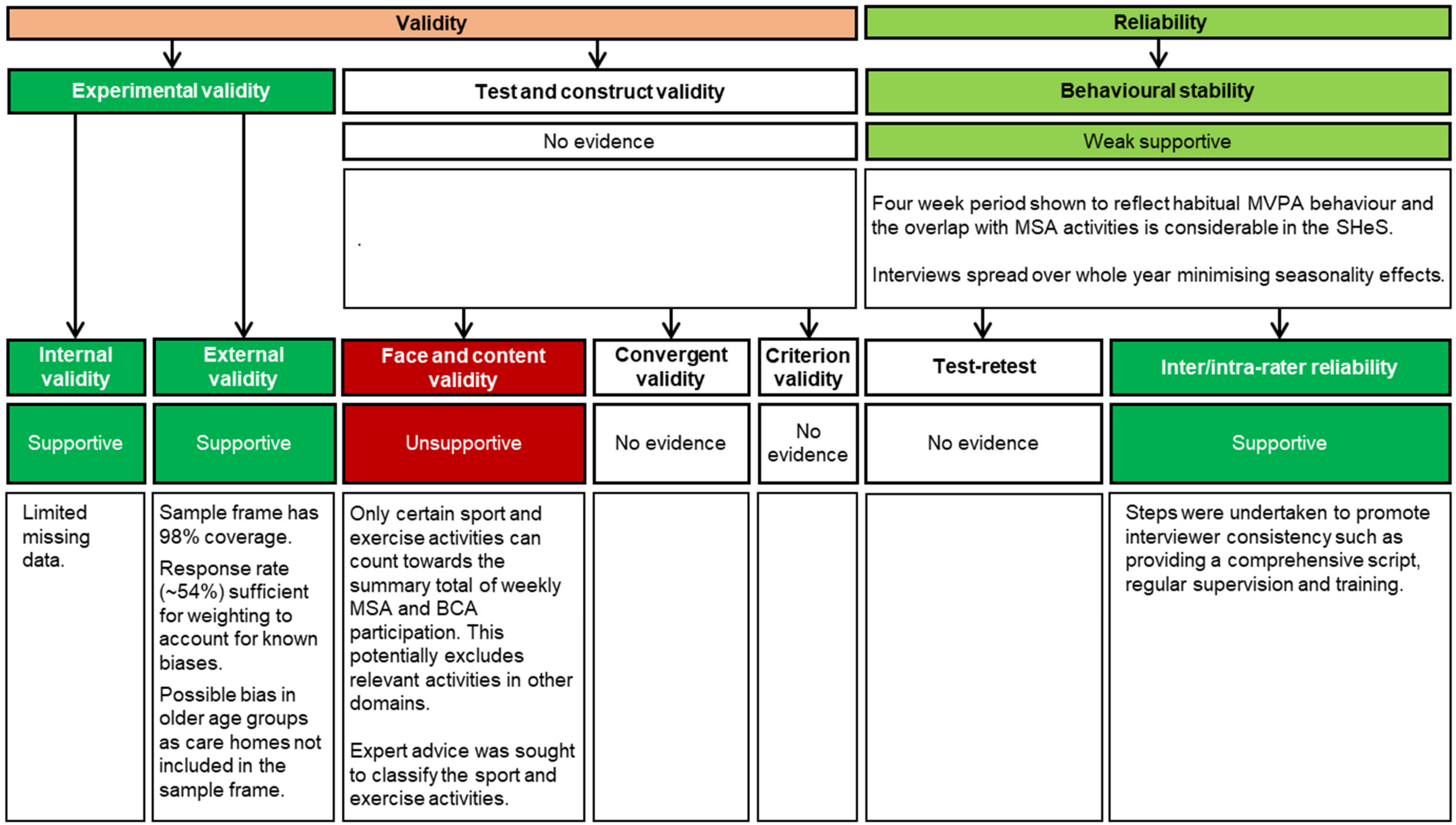

Figure 15. Summary of Validity and Reliability Evidence Concerning the Measurement of Muscle Strengthening and Balance and Co-ordination Activity by the 2012-15 Scottish Health Survey.

BCA = balance and co-ordination activity; MSA = muscle strengthening activity; MVPA = moderate-to-vigorous physical activity; SHeS = Scottish Health Survey.

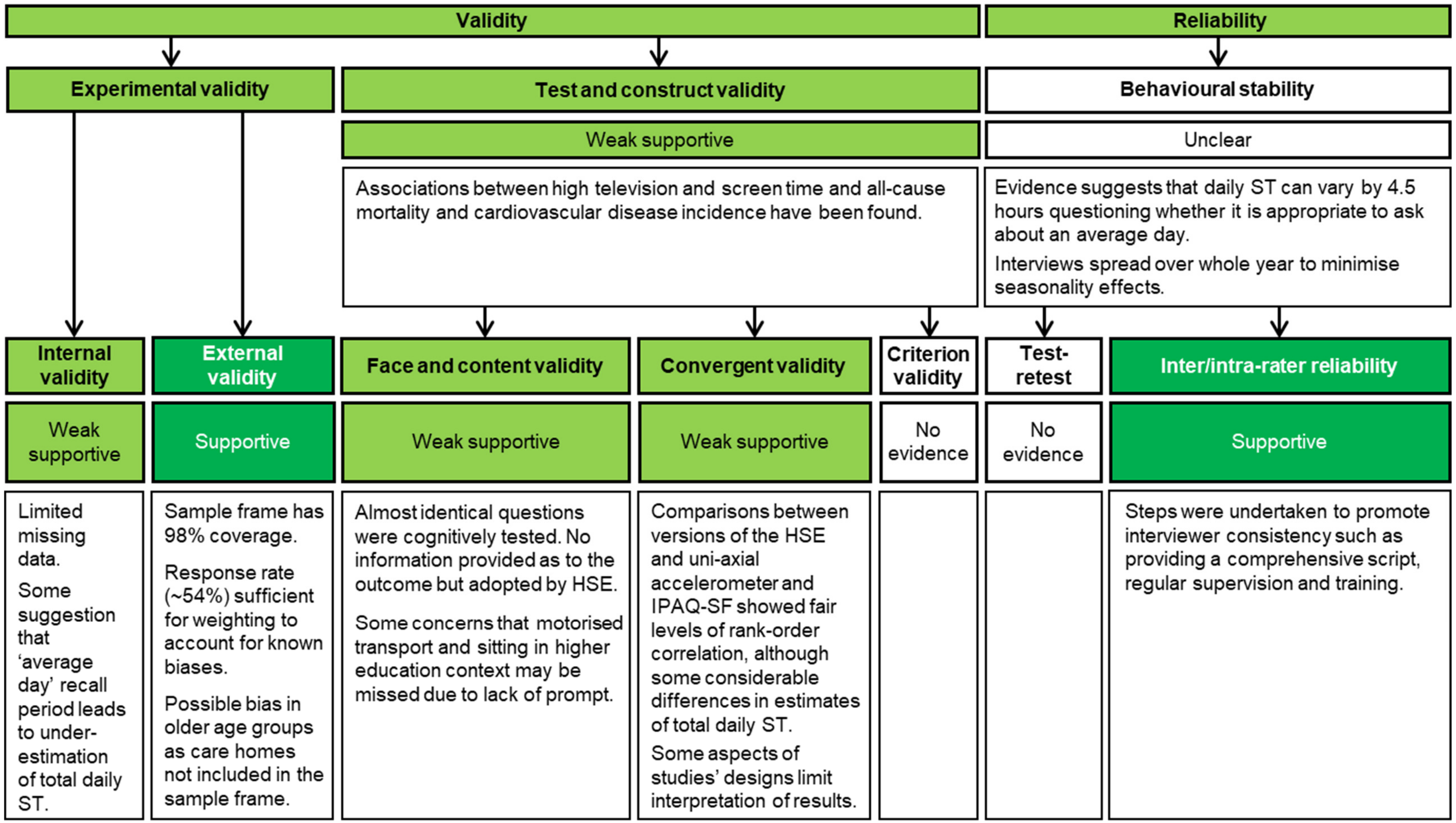

Figure 16. Summary of Validity and Reliability Evidence Concerning the Measurement of Sedentary Time by the 2012-15 Scottish Health Survey.

HSE = Health Survey for England; IPAQ-SF = International Physical Activity Questionnaire Short-Form; ST = sedentary time.

9.5 Discussion

9.5.1 Principal findings

There is evidence that the results of Studies 1-3 are valid and reliable but with several important caveats: (1) the interpretation should focus on non-occupational MVPA, (2) it should be clear that MSAs and BCAs are limited to the domain of sport and exercise activities, and (3) the main conclusions relating to ST should be based on relative comparisons between groups rather than absolute values. This supports my decision to undertake the analyses for Study 1 with and without occupational MVPA, and to regularly include the phrase ‘sport and exercise activities’ in the published paper for Study 2 to clarify the limitations of the method. As described in Section 8.7, I was able to incorporate the relevant findings into Study 3 in time for publication. The supportive ratings for the internal and external validity were important as they indicated the results could be generalised to adults living in private households in Scotland. There is one caveat to this: analyses focussing on older age groups should acknowledge that those in care homes were not included in the sample frame.

9.6 Comparison with Alternative Measurement Methods

9.6.1 Moderate-to-vigorous physical activity

The evidence collected as part of Study 4 indicated that the 2012-15 SHeS MVPA measurement method had convergent validity properties are similar to most other self-report instruments. Helmerhorst, Brage, Warren, Besson, and Ekelund (2012) found correlation coefficients of most self-reported PA questionnaires to fall in the range of 0.25-0.40 when compared against objective measures across a range of summary measures.

However, I also found evidence of other research that had highlighted concerns with the domain of occupational MVPA (e.g. Joint Health Surveys Unit, National Centre for Social Research, & University College London Research Department of Epidemiology and Population Health, 2007). In light of this, I considered the alternative measures for this domain (see Appendix 23) that could be incorporated into the main questionnaire, minimising the disruption to domain-specific trend data.

My preferred option was to adopt the questions used by the HSE (R. Craig & Mindell, 2013). These were derived from the European Prospective Investigation of Cancer - Norfolk study, and revised by an expert panel after cognitive testing (Joint Health Surveys Unit et al., 2007). In addition to addressing face and content validity concerns, there was tentative evidence to suggest this would improve measures of convergent validity when compared with objective measures. The correlation coefficients were higher when these questions were used for occupational MVPA, as opposed to a method very similar to the 2012-15 SHeS method (Joint Health Surveys Unit et al., 2007). Another advantage is that the HSE and SHeS measurement instrument would be almost entirely identical, and country comparisons could then become meaningful. However, this would add approximately six questions to the SHeS questionnaire (exact numbers depend on responses) which would be an ambitious request given the length of the current PA module.

9.6.2 Muscle strengthening and balance and co-ordination activities

Alternative measurement instruments for the surveillance of MSA and BCA have briefly been described in Section 7.7. As part of additional work relating to Study 2, I compiled a list of the measurement instruments for MSA used in large cohort studies (see Appendix 14). If anything, these questions are narrower in scope that the 2012-15 SHeS measurement and analysis method. For example, MSAs are often limited to lifting weights or exercises using own body weight, and aerobic activities such as cycling are excluded. As this further exacerbates the content validity concerns, it is hard to justify changing the measurement instrument at present.

9.6.3 Sedentary time

The findings of Study 4 do not present any major reasons to change the SHeS measurement instrument: the evidence is mostly supportive. Validity and reliability studies on self-report questionnaires such as the IPAQ or Global Physical Activity Questionnaire (GPAQ) do not present compelling evidence that they would be preferable alternatives (Cleland et al., 2014; Rosenberg, Bull, Marshall, Sallis, & Bauman, 2008). Both the IPAQ and the GPAQ are single item questions asking about total daily ST (although the IPAQ long version distinguishes between weekdays and weekend days). The results of a study by Clemes, David, Zhao, Han, and Brown (2012) suggest that questionnaires that sum behaviours improve the estimates of total ST. This provides further support for using the 2012-15 SHeS questionnaire over the IPAQ and GPAQ.

This conclusion was supported by academics at Glasgow Caledonian University (Drs Philippa Dall and Sebastien Chastin, personal communication). Based on experience of comparing multiple self-report instruments, they agreed that no other widely used method would improve the estimates of total ST. However, their latest research had led them to develop a novel series of questions. As Figure 17 shows, they requested my help to communicate with the relevant people in policy and surveillance in Scotland to propose these were incorporated into the SHeS. I was able to assist, resulting in their proposal undergoing cognitive testing prior to the 2018 SHeS. It is not possible to include details of the proposed changes or the outcome of the cognitive testing that ScotCen undertook, as this is the intellectual property of others. However, at the time of writing, myself and the academics at Glasgow Caledonian University agreed on three points regarding the SHeS measurement instrument: (1) that there was limited merit in replacing it with other widely used self-report instruments, (2) that there was the potential for minor improvements through the proposals they suggested, and (3) if no changes were made, then the reporting of total ST in the Annual Reports must include ST at work into. The latter point will be discussed in Section 9.7.

9.7 Implications for Surveillance

Figure 17 shows how the work in this thesis has informed surveillance of MVPA, MSA, BCA, and ST in Scotland and has the potential to continue to do so. There are three key pathways for this (1) through my personal invitation to advise on potential future changes to the SHeS measurement instrument, (2) through work undertaken as part of the U.K. CMOs' Muscle and Bone Strength and Balance Expert Group, and (3) by sharing analysis code to ensure that future reporting of total ST in SHeS Annual Reports includes ST at work.

In the final weeks of writing this thesis, myself, Professor Nanette Mutrie MBE and Dr Paul Kelly were invited to discuss potential changes to the SHeS PA and ST measurement instruments with ScotCen and the Scottish Government. It is not appropriate to describe the content of those discussions at this time as no final decisions have been made. However, it is worth reflecting on the reasons for my invitation and my experiences of the process as there are implications for academic researchers who want to engage with established national surveys.

As Figure 17 shows, my invitation was likely due to a combination of the specific work around the validity and reliability of the questionnaire undertaken in Study 4 as well as the professional network I had developed. By November 2017, I was in a unique position in Scotland as having experience of the academic research community (through this PhD), policy and surveillance management at the Scottish Government (through a three-month internship in 2016), and the day-to-day running of national surveys (through previous employment at ScotCen in 2011-2012). This was important because I was able to understand the competing priorities, and therefore propose appropriate solutions.

An example of this was understanding the importance of time-constraints on a large survey. If the SHeS is too long then field-work costs increase beyond those budgeted for, and response rates may be affected. These factors are not always as apparent in one-off, smaller scale research projects that academic researchers may be more familiar with. The PA and ST module is already one of the longest in the SHeS and so adding further questions is almost impossible. This was relevant when considering how to improve the measurement of occupational MVPA: it is hard to find a solution that does not add further questions and maintains the questionnaire for the other domains. It was important for me as an academic researcher to accept these constraints them rather than arguing against them, or debating the relative merits of occupational MVPA questions over those on another health topic. Not only is this a narrow minded way of improving population health surveillance, but it is likely to be detrimental to the professional relationship and so may hinder future efforts to improve PA and ST surveillance.

A second way in which this work has the potential to inform surveillance is through the U.K. CMOs’ Expert Group for Muscle and Bone Strengthening and Balance. I was invited to be part of it following the publication of Study 2. The first meeting of the group was in London in July 2017 and Study 2 was a key reference text circulated to all members. Although I was unable to attend, I shared additional work on alternative MSA measurement instruments used in large cohort studies (see Appendix 14) via Professor Nanette Mutrie MBE. After the meeting, I was invited to join a sub-group was set up to consider surveillance issues in more detail. This work will feed in to the 2018 update of the U.K. PA guidelines. This has the potential to be very beneficial for the surveillance of MSA and BCA in Scotland.

The third pathway through which the work in this thesis may inform surveillance is through the reporting of total weekday ST. The justification for this came from Study 3 which demonstrated the implications on the age-related differences in total ST when ST at work was included in the estimates. However, the timing of my communication with SHeS survey manager at the Scottish Government was greatly dependent on the proposals from Glasgow Caledonian University to change the ST questions altogether. At the time of writing, this situation is not fully resolved, but a proposal explaining the change in reporting has been sent.

Figure 17 indicates that many of the attributes that describe the policy-making process (see Chapter 5) apply to surveillance too. For example, decisions were not based on research evidence alone but usually a result of multiple factors such as questionnaire time constraints or the reliance of policies on trend data. The importance of personal relationships (Giles-Corti et al., 2015) was apparent, as was the iterative nature of the process (Brownson, Royer, et al., 2006).

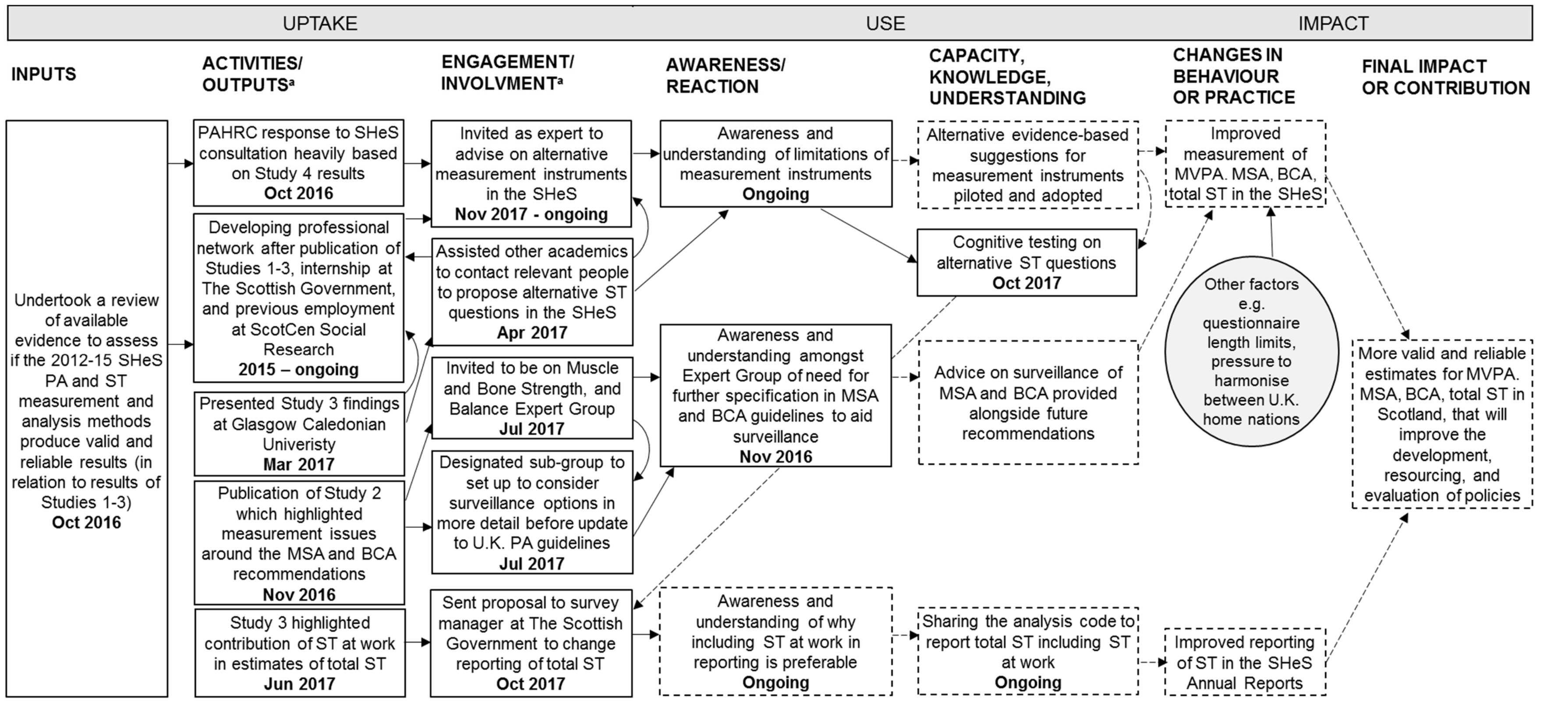

Figure 17. Tracing the Impact of Study 4.

Based on the Pathway for Impact from Morton (2015). Continuous arrows represent connections that evidence supports (see Appendix 23); dashed lines represent plausible connections. [a]Activities/Outputs covers broad knowledge exchange activities, Engagement/Involvement covers user interactions. BCA = balance and co-ordination activity; GCU = Glasgow Caledonian University; HEPA Europe = European network for the promotion of Health-Enhancing Physical Activity; MSA = muscle strengthening activity; MVPA = moderate-to-vigorous physical activity; PA = physical activity; PAHRC = Physical Activity for Health Research Centre; SHeS = Scottish Health Survey.

9.8 Strengths and Limitations

This study is the first transparent, documented assessment of the available validity and reliability evidence for the 2012-2015 SHeS PA and ST measurement methods. The novel and comprehensive collection and synthesis of evidence has resulted in a nuanced understanding of where the strengths and weaknesses of the methods lie. As described, this has greatly strengthened the interpretation of the results of the thesis and heavily influenced efforts to improve future surveillance of MVPA, MSA, BCA, and ST.

The conclusions of the study are limited by the lack of evidence for some sub-components. One could argue that some of these sub-components, such as test-retest reliability, are more relevant to intervention rather than surveillance studies (Masse & de Niet, 2012). Therefore, the lack of evidence is not of major concern. Nonetheless, higher quality convergent or criterion validity evidence across all research questions would have enabled more robust conclusions to be drawn.

The assessment is also heavily dependent on the ratings allocated to the sub-components. Although the factors considered were clearly stated in the methods, this was a subjective process undertaken by a researcher reliant on the data. In an effort to minimise potential bias, ratings were confirmed with Dr Paul Kelly and Dr Claire Fitzsimons.

It was also challenging to define 'relevant' evidence. No formal search strategy criteria were set out at the start of the project, and subjective judgement had to be used to find a balance between relevance and level of detail. This was advantageous as it meant studies such as that of Dall et al. (2017) that were not specific to the SHeS or a similar survey could be included. Given this was the first ever use of the EF in this way, it was prudent not to constrain the review based on pre-conceived ideas of the nature of relevant evidence. However, it is possible that relevant information was missed or excluded due to the non-systematic search strategy.

9.9 Conclusions

The results of this evidence review suggest that the results of Studies 1-3 are valid and reliable with certain key caveats that have been taken into account. Studies 1-4, and the knowledge I have gained from undertaking them, have been and will continue to be influential in informing future surveillance of PA and ST in Scotland.

Chapter 10: Planning Study 5

10.1 Initial Proposal

In Year 1, the PhD Steering Group advised delaying the decision on the research objective(s) for Study 5 so that the learning from and findings of Studies 1-4 could inform it (see Section 5.1). This was also partly due to concerns with the initially proposed plans. I had intended to focus on the change to the MVPA recommendation (5x30 to 150 mins). Using the 2012-15 SHeS datasets linked to health records, I intended to compare the prospective health outcomes of (i) those meeting both 5x30 and 150 mins, (ii) those meeting 150 mins only, and (iii) those meeting neither. The differences between (i) and (ii) would have given an indication as to whether there were additional health benefits from more frequent bouts of MVPA.

The PhD Steering Group advised that the main policy interest was on the 'new' recommendations (MSA, BCA, and ST) and it was not obvious how the results of the initially proposed project would substantially influence current PA policy in Scotland. There was also an issue of timeliness. It was likely a guideline review would be underway by the time of publication, or that others may have published on this issue. Both turned out to be the case: the U.K. PA guidelines will be reviewed in 2018, and O'Donovan, Lee, Hamer, and Stamatakis (2017) published an almost identical study to the one proposed. The study found that, compared with those reporting no MVPA, all groups had a reduced risk of ACM, CVD, and cancer mortality, regardless of pattern or volume.

Table 8. The Advantages and Disadvantages of Potential Research Objectives for Study 5

	Alternative research objective	Advantages	Disadvantages
1	Investigate the effects of MSA and BCA participation on health outcomes.	Few nationally representative studies exist, and those that do are predominantly based on U.S. samples.	Concerns regarding the content validity of the method Could limit the findings. Also, MSAs and BCAs were almost entirely a subset of MVPA and so adjustment for MVPA could be problematic.
2	Investigate the effects of ST on health outcomes.	The dose-response relationship between total ST and health outcomes is unclear. This work could potentially inform a quantified recommendation and/or policy indicators.	The results of Study 4 indicated that the SHeS measurement instrument is not optimal for estimating total ST. This objective would be better addressed through analysis of inclinometer data. Also, there was greater policy interest in the combination of ST and other health behaviours' effects on health rather than considering them in isolation.
3	Investigate the effects of ST and MVPA on health outcomes.	The combined effects were of policy and academic interest. Study 4 findings indicate that categorising ST and MVPA could be most appropriate way of summarising the data.	A decision on how what value categorise ST would be necessary that could be interpreted as a recommendation.
4	Investigate the effects of meeting all the recommendations on health outcomes.	This would be a novel analysis of policy interest.	There were very low numbers for certain combinations of recommendations, collinearity may be an issue. A decision on how what value categorise ST would be necessary that could be interpreted as a recommendation. It was unclear whether the guidelines were meant to be interpreted in this combined way.

Note. BCA = balance and co-ordination activity; MSA = muscle strengthening activity; MVPA = moderate-and-vigorous physical activity; ST = sedentary time; SHeS = Scottish Health Survey.

10.2 Alternative Research Questions and Justification of Decision

Table 8 presents the alternative research objectives that arose whilst working on Studies 1-4. Research objective 3 was selected because of the strong policy interest, the compatibility of the analysis with the recommendations of Study 4, and as the research question did not specifically mention the guidelines, categorisation of ST would not necessarily require a recommended dose.

10.3 Data Availability

The intention was to undertake analysis on the 2012-15 SHeS datasets linked with health record data up until 31st December 2015 (see approved Confidential Data Release request in Appendix 24). These would have had 0-4 years of follow-up; within the range of other published prospective cohort studies (Celis-Morales et al., 2017). However, it would have been hard to fully account for reverse causality. One should exclude any cases that have the event of interest in the first two years of follow-up in order to minimise the risk of underlying health conditions present at baseline being the reason for high ST or low MVPA. With a maximum of four years of follow-up, this would have reduced the number of events included in the analyses and therefore increased the uncertainty.

July 2017 was the planned release date for these data. To ensure this work would be completed within the funding period and University of Edinburgh submission requirements, I requested the most up-to-date datasets as of January 2017 to prepare the analysis code in advance. These were the 2012-14 SHeS datasets with health record data up until 31st December 2014. Despite regular contact between myself and the data providers between January-July 2017, I was informed in June that the 2012-15 SHeS datasets linked with health records up until 31st December 2015 would not be available. This was due to circumstances at the

Scottish Government (precise details unclear) that delayed the authorisation of any further linkage updates.

Although options using older SHeS datasets were considered, I concluded it was preferable to continue to investigate the planned research objective (option 3 in Table 8). This could not be undertaken with the datasets prior to 2012 because they did not ask about total ST. I had already developed the analysis plan (and code) and had identified areas of methodological interest. This process is often overlooked in favour of focussing on the interpretation of the results, yet decisions made may have profound implications.

Study 5 is therefore a preliminary investigation of the research question, where the protocol and analysis code for the final analyses have been developed (see Appendix 25 for an overview of the timeline of tasks for both the preliminary and final analysis). Delaying the final analysis also allows for a longer follow-up period, to alleviate the previous concerns around accounting for reverse causality. If further funding is necessary for the final analyses then I will look for relevant calls from funders such as the ESRC who often support secondary analysis of datasets stored in the U.K. Data Archive.

Chapter 11: Study 5 – An Investigation into the Joint Effects of Moderate-to-Vigorous Physical Activity and Sedentary Time on Non-Communicable Disease Outcomes

Study 5 is a preliminary analysis into the joint effects of non-occupational MVPA and total ST on the risk of ACM, CVD-related events or mortality, malignant cancer diagnosis or death, and episodes with a principal or non-principal diagnosis of diabetes. It is presented in the form of an extended manuscript that also discusses how these methods will be applied to the final analyses (planned for 2022; see timeline in Appendix 25). I led all the work in this chapter, developed the methods, undertook the analyses, and wrote the chapter. Dr Paul Kelly and Dr Claire Fitzsimons assisted at all stages in a supervisory capacity.

11.1 Background

Section 8.1 described the evidence that supports considering high ST as an independent risk factor for ill health. In this section, I will justify why it is also appropriate to consider the joint effects of MVPA and total ST, and why this may be the most appropriate way to include both behaviours in statistical models.

11.1.1 Adjusting for moderate-to-vigorous physical activity

Studies that have concluded there is an 'independent' effect of high ST on health have often 'adjusted' for MVPA in their statistical models (e.g. Stamatakis, Hirani, et al., 2009; Warren et al., 2010). Adjustment removes the effect of a potential confounder on the health outcome so the estimate only reflects that of the variable of interest. Adjustment is appropriate if the relationship between the variables are as shown in Figure 18.

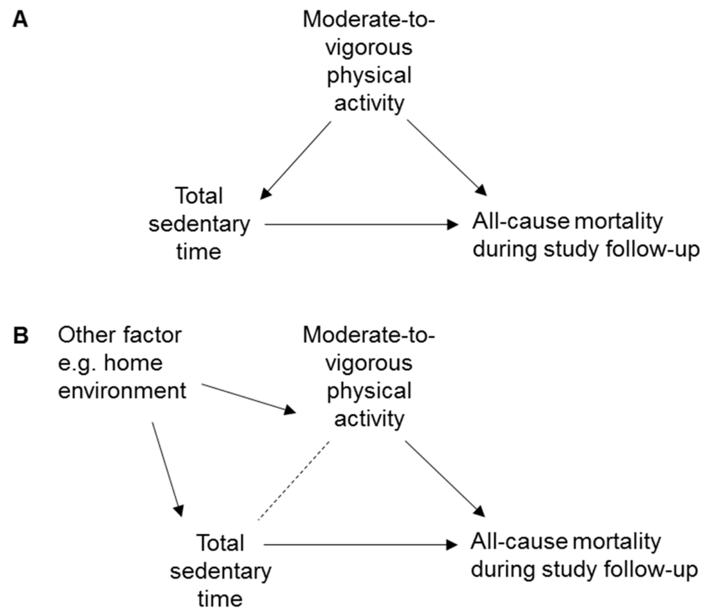

Figure 18. Causal Diagrams of Two Possible Relationships Between Moderate-to-vigorous Physical Activity and Total Sedentary Time.

Adapted from Page, Peeters, and Merom (2015). Continuous arrows represent a causal relationship, dotted lines represent unknown relationship. A = Moderate-to-vigorous physical activity is a cause of sedentary time and all-cause mortality. B = Moderate-to-vigorous physical activity and sedentary time have a common cause (e.g. home environment). Both of them increase the risk of all-cause mortality.

11.1.2 Stratifying by moderate-to-vigorous physical activity level

Stratification is advisable when there is effect modification (an interaction effect). An example of this is when the relationship between ST and the health outcome differs by level of MVPA. The meta-analysis by Ekelund et al. (2016) is the strongest evidence to date that MVPA modifies the relationship between ST and ACM and CVD mortality. Ekelund et al. (2016) found that within each of the bottom three MVPA quartiles, the risk of ACM increased with increasing ST (see Figure 19). However, the risk was attenuated with increasing MVPA. In the top MVPA quartile, the relationship between ST and ACM was eliminated. Very similar patterns were evident when the outcome was CVD mortality. For cancer mortality, only those in the lowest MVPA quartile had in an increase in risk with increasing ST.

This study is a key reference in the field of PA and SB epidemiology. The authors pooled data from 13 studies with a follow-up time of between 2-18 years, generating a total sample size of 1,005,791 individuals. There were 84,609 deaths, sufficient for calculating estimates with an appropriate degree of certainty. The component studies included some of the key references in the field of research up until this point (e.g.Katzmarzyk, Church, Craig, & Bouchard, 2009; Matthews et al., 2012; van der Ploeg, Chey, Korda, Banks, & Bauman, 2012). They were from seven different countries on four continents, increasing the generalisability of the findings.

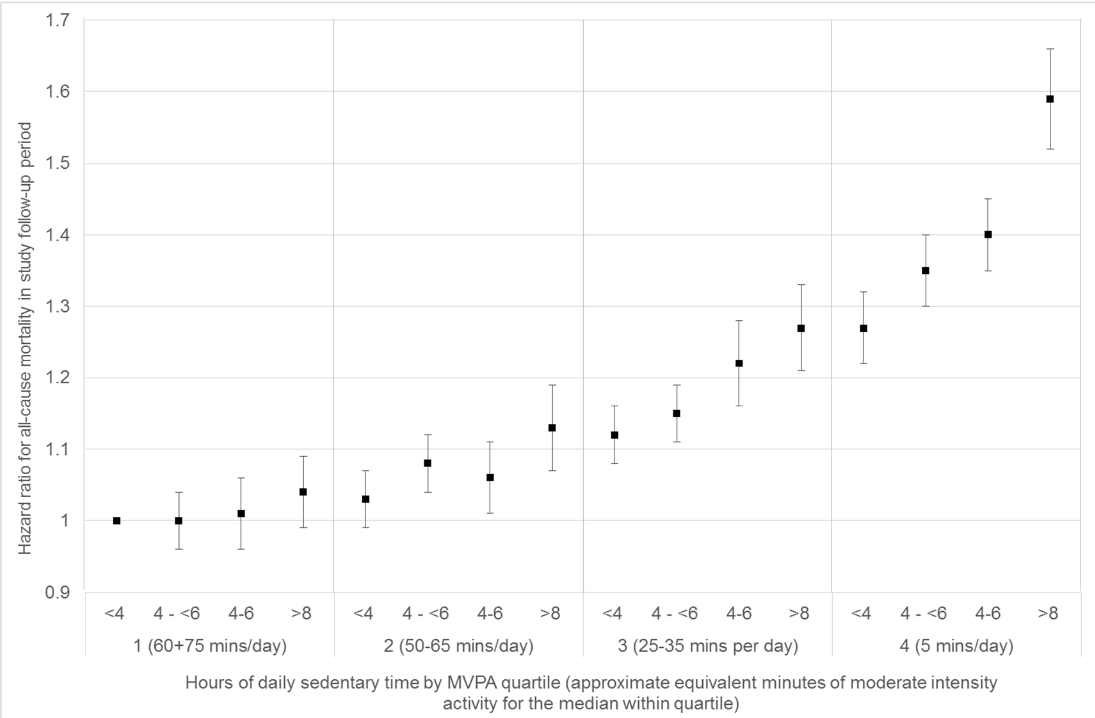

Figure 19. The Results of Ekelund et al. (2016) Investigating the Joint Effects of Total Sedentary Time and Moderate-to-vigorous Aerobic Intensity Physical Activity Levels on All-cause Mortality.

MVPA = moderate-to-vigorous physical activity.

11.1.4 Collider bias

It is important to consider the underlying relationships between these variables because adjusting for or stratifying by MVPA inappropriately may induce a spurious relationship between ST and a health outcome. This could occur if the relationship between MVPA and ST is not as shown in Figure 18 but instead as shown in Figure 20 (i.e. MVPA is caused by ST and the outcome of interest). Assume also there is no 'true' relationship between ST and obesity. If MVPA was adjusted for in this scenario, a spurious relationship may be induced (as represented by the dotted arrow; see Appendix 26 for worked example). This is a theoretically plausible scenario although the current evidence is not sufficient to support or refute the described relationship between MVPA and ST.

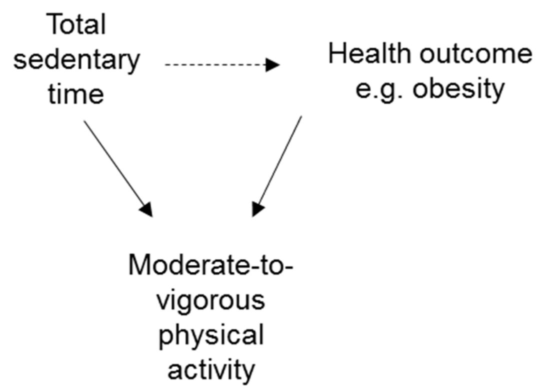

Figure 20. Causal Diagram of a Possible Relationship Between Moderate-to-vigorous Physical Activity and Total Sedentary Time.
Adapted from Page et al. (2015). Continuous arrows represent a causal relationship, dotted arrow represents a spurious relationship that might be induced.

Another possible scenario where adjustment would be inappropriate is if MVPA was on the causal pathway between ST and the health outcome (see Figure 21 for two examples). This is termed over-adjustment bias because the overall effect of ST on the health outcome is underestimated as it removes one mechanistic pathway (Schisterman, Cole, & Platt, 2009).

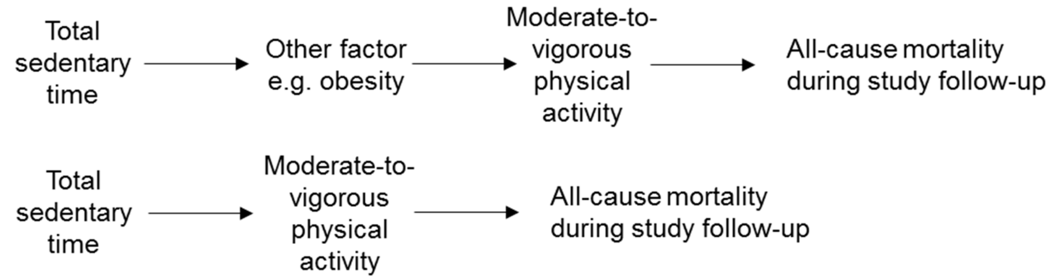

Figure 21. Causal Diagram Showing Possible Pathways Between Sedentary Time and All-cause Mortality.

11.1.5 Joint effects of moderate-to-vigorous physical activity and sedentary time

Based on the uncertainties highlighted, I felt the most appropriate method of considering the relationship between MVPA and/or ST and health outcomes was to investigate the joint effects. This avoids the need to stratify or adjust and therefore make a judgment about the relationship. It involves creating mutually exclusive categories of exposure to the two risk factors. It allows for comparisons across levels of both MVPA and ST (stratification would not) and avoids the need for interaction terms when effect modification is present (adjustment would). As described in Studies 2 and 3, interaction terms are complicated to interpret and communicate. This is exacerbated as adjusting for the complex sampling limits the availability of statistical test commands in software such as STATA (StataCorp, Texas, U.S.). As the research question is to investigate the joint effects, concerns around over-adjustment for each behaviour do not apply. As investigating the joint effects did not compromise the research question in any way, it felt most appropriate to use given the uncertainty around the causal relationship between MVPA and ST.

11.1.6 Time-scale choice in Cox proportional hazard models

Cox proportional hazards models (Cox, 1972) are the most commonly used statistical models for 'time-to-event' analyses because they allow the underlying risk of event to vary over the follow-up period. However, one decision that is commonly overlooked in the field of PA and ST epidemiology is the choice of time-scale used in the model. Data are usually available so that the follow-up period can be considered in terms of time since interview, the participants' age, or calendar time. This is important because the time-scale determines how the cases are compared against each other. Every time an event occurs, an instantaneous risk of that event occurring is calculated. This involves comparing all others who were potentially at risk at the time (the risk set). These are then combined to estimate the overall hazard ratio for the follow-up period.

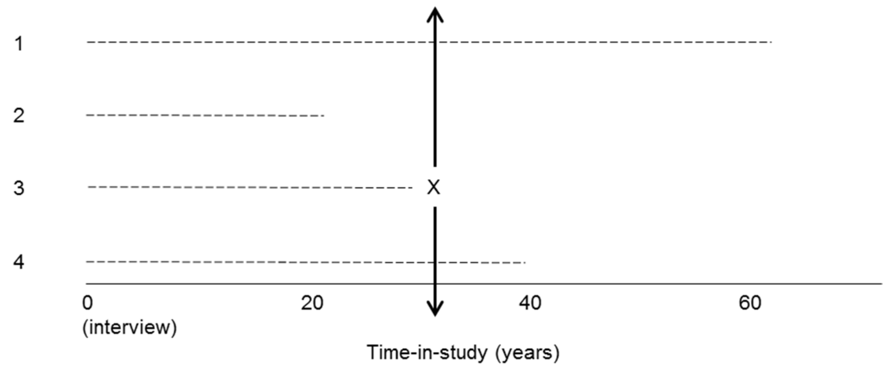

Figure 22. A Cox Proportional Hazards Model Risk Set with Time-in-study as the Time-scale.
X = event of interest; arrow reflects the risk set comparison.

Figure 22 is an example of using time-in-study as the time-scale. Time zero is the date of interview for all participants. In this situation, the crude (unadjusted for covariates) risk set for participant 3's event consists of participants 1 and 4 (i.e. all participants in the study at approximately 30 years post-interview). Participant 2 is not included in this comparison because they have dropped out of the study before the event occurs.

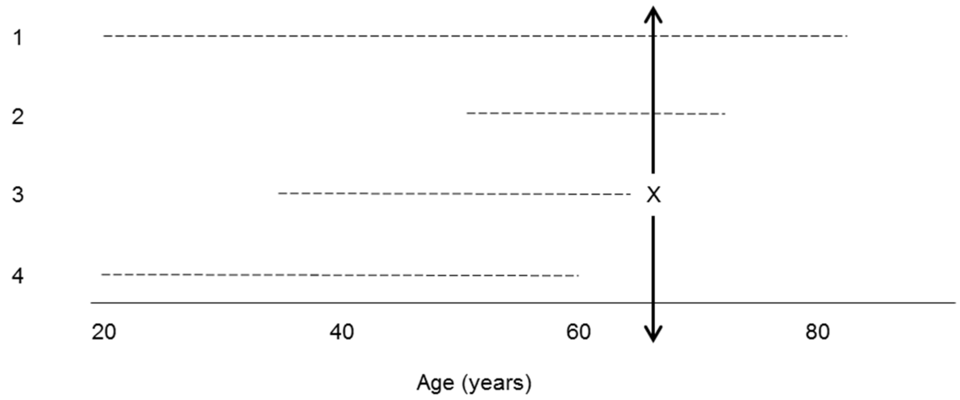

Figure 23. A Cox Proportional Hazards Model Risk Set with Age as the Time-scale. X = event of interest; arrow reflects the risk set comparison.

Figure 23 shows the same data rearranged if age was used as the time-scale (i.e. time zero is birth date). As the participants were interviewed at different ages, their entry to the study appears staggered. Participant 3 had their event at approximately 65 years of age. The risk set therefore comprises of all others in the study at this age (Participants 1 and 2). Participant 4 dropped out of the study at age 60 and so is not included in this risk set. This shows how the choice of time-scale could plausibly lead to different results from the same raw data.

Many statisticians recommend using the time-scale that has the strongest association with the outcome (Korn, Graubard, & Midthune, 1997; Thiebaut & Benichou, 2004). This is most likely to be age for those investigating chronic disease outcomes. The alternatives of time-in-study or calendar time are unlikely to have as strong as association, if any, with the outcome.

Despite the theoretical grounds for age being the optimal time-scale choice within the field of PA and SB epidemiology, it is not the convention. Most papers do not mention it, and so one assumes they use the ‘default’ of time-in-study (Gebel et al., 2015; Matsunaga et al., 2017; Oja et al., 2017). However, there are some examples of studies using age as a time-scale (Long et al., 2015; Wijndaele, Sharp, Wareham, & Brage, 2017; Zhao et al., 2014), and even some who have used calendar time due to the pooling of cohorts over a 20-year period (O'Donovan et al., 2017). As the research questions of these studies differ greatly it is hard to understand what effect the choice of time-scale may have on the results. Therefore, I will undertake sensitivity analyses to investigate the effect in relation to the current research question.

11.1.7 Research questions

Based on the background presented in Chapter 10 and Section 11.1, the research question was finalised as: what are the joint effects of non-occupational MVPA and total ST on four health outcomes (1) ACM, (2) CVD-related events or mortality, (3) malignant cancer diagnosis or death, and (4) episodes with a principal or non-principal diagnosis of diabetes amongst adults in Scotland. A secondary question was to investigate the effect of the choice of time-scale used in the Cox proportional hazards models. This chapter presents the preliminary results; final analyses will be undertaken according to the timeline described in Appendix 25.

CVD, cancer, and diabetes were chosen as outcomes as they are three of the four conditions included in the WHO 2025 NCD reduction target (WHO Regional Office for Europe, 2016); a measure of the fourth (chronic respiratory diseases) was not provided on the dataset.

11.2 Methods

11.2.1 Data sources, samples, and ethical approval

The preliminary analyses use the 2012-14 SHeS datasets linked to health records up until 31st December 2014. Ethical approval for their use was received on 24th April 2016 after an application for Confidential Data Release to ISD of NHS HS (see Appendix 24).They were transferred from ISD using the secure file transfer protocol on the 3rd March 2017. The 2012-14 SHeS interview datasets were downloaded from the U.K. Data Archive on the 17th December 2015, after agreement to the conditions of the End User License (see Appendix 4). These archive datasets were used to add the weighting variable. The 2012-15 SHeS interview datasets were also downloaded from the U.K. Data Archive on the 7th August 2017. They were used with the 2012-14 SHeS interview datasets to predict the sample size of the planned final analyses. Figures 24 and 25 provide an overview of these data sources and their present and future use.

The preliminary analysis sample is defined as those with complete health record and exposure data in the 2012-14 SHeS sample. It consisted of 11,481 adult (≥16 years) respondents. Assuming similar linkage and missing data rates for the 2015 SHeS sample, the expected unweighted 'final analysis sample' will include 13,333 adult respondents (see Figure 24). The preliminary analysis sample has an approximate average follow-up of 1.5 years (range 0-3 years); the final analysis sample will have an approximate average of 7 years (maximum of 9 years). This should mean a sufficient number of events occur to have appropriate confidence on the estimates. This should also mean the results are available in time to feed into any PA policy discussion that occurs as the LMSMA 2022 target is evaluated (see Section 4.3; Scottish Executive, 2003).

An internal ethics application was also submitted to the Moray House School of Education committee in April 2017. This was for documentation processes only, not to revaluate the permissions granted by ISD. The internal application was submitted after work on the project had begun because the procedure for secondary analysis projects had to be adapted in order to provide adequate description of the ethical issues and steps taken to mitigate them. In response to this experience, I submitted recommendations for improving the system (see Appendix 27).

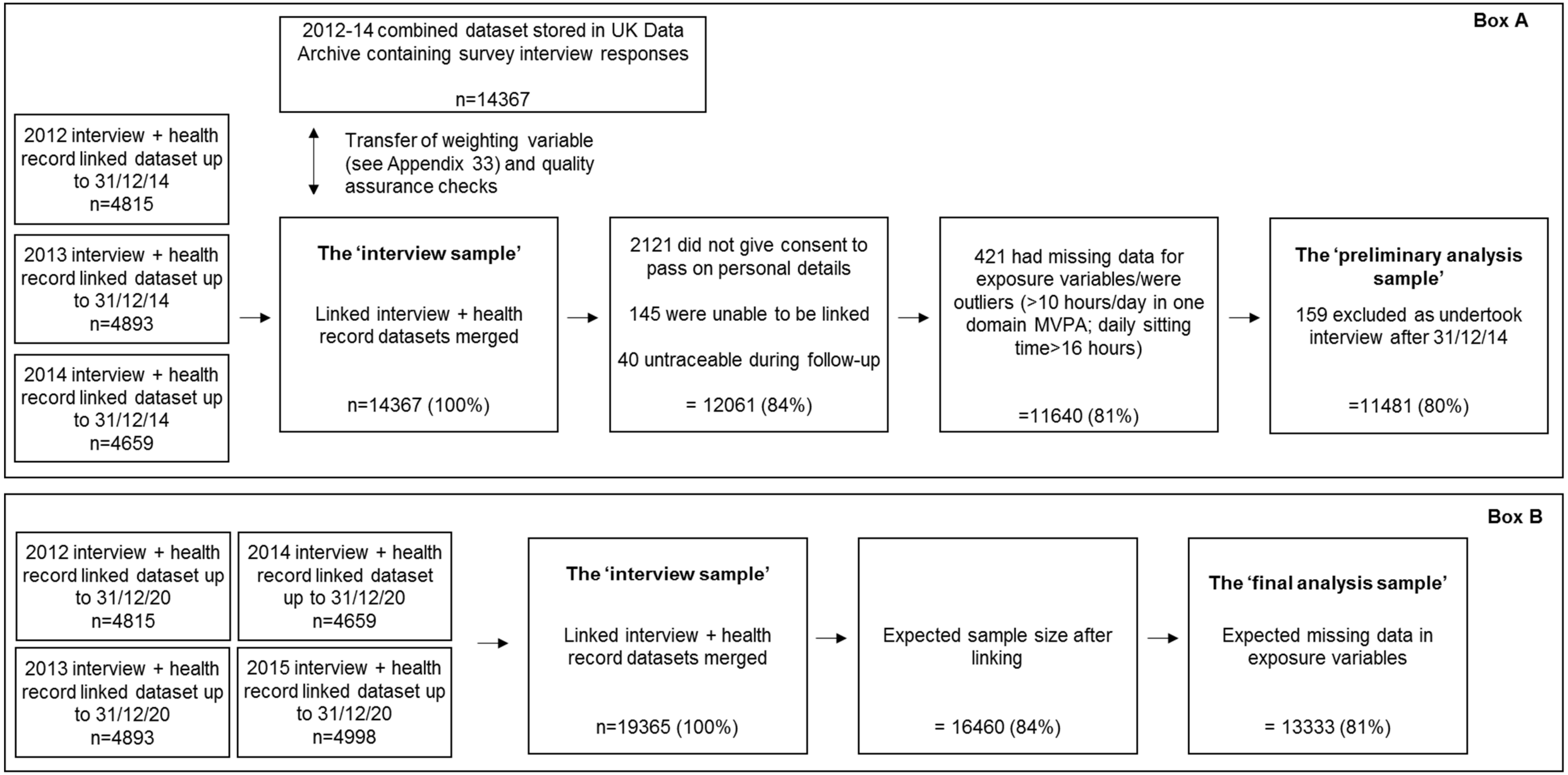

Figure 24. The Preliminary and Final Analyses Samples.

Box A covers the data used in the preliminary analyses. This has been used to predict the sample sizes for the final analyses shown in Box B.

Dataset		Year of follow up								
		2012	2013	2014	2015	2016	2017	2018	2019	2020
Survey year	2012	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
	2013		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
	2014			0-1	1-2	2-3	3-4	4-5	5-6	6-7
	2015				0-1	1-2	2-3	3-4	4-5	5-6
Approximate mean follow-up (years)		0.5	1	1.5	2	3	4	5	6	7

Figure 25. Datasets and Follow-up Periods for the Preliminary and Final Analyses. Black refers to the data used in the preliminary analyses, grey refers to the additional data that will be included in the final analyses. No significant differences in drop-out rates between survey years or over the study duration are expected.

11.2.2 Exposure measures

The 2012-15 SHeS MVPA and ST questionnaire is included in Appendix 6 and described in detail in Section 4.4. The data were processed as if they were to be included in the meta-analysis by Ekelund et al. (2016): MVPA was converted into MET-hours per day and split into quartiles, and ST was categorised using commonly reported boundaries with consideration of the sub-group sizes. This will enable comparisons with what is currently the key reference for this field. In line with findings from Study 4, only non-occupational MVPA was included. Outliers were determined in the same ways as for Studies 1 and 3: >10 hours per day in one domain of MVPA and/or total daily ST >16 hours.

MET values were assigned to each individual activity according to the closest match in the 2011 Compendium of Physical Activities (Ainsworth et al., 2011; see Appendix 28). These were multiplied by the reported duration in hours, summed to give a daily average, and split into quartiles. Sensitivity analyses found that 93% of the analysis sample remained in the same quartile whether measured in MET-hours or intensity-adjusted minutes per day. These were not expected to be identical as the MET classifications ‘weights’ MVPA on a more detailed intensity scale compared to simply doubling the minutes of vigorous intensity activity. However, one would expect them to be highly correlated.

Daily weekday ST was calculated by adding the responses to the questions on (1) sitting time at work (where applicable), (2) weekday leisure TV/screen time, (3) any other weekday leisure ST. Daily weekend day ST was calculated by adding the respective responses to (2) and (3). Average daily ST was calculated by weighting weekday and weekend day totals in the ratio 5:2.

To ensure there was a sufficient number of events in each category (a key factor in reducing uncertainty of estimates), the present study used two categories of total ST: < and ≥ 8 hours per day. This matched one of the categories from Ekelund et al. (2016); they split ST into 2-hour categories up to ≥ 8 hours per day. The 8-hour boundary was chosen because other literature suggests that there is a greater increase in health risk for every hour of ST above a threshold in the region of 7-10 hours than below it (Chau et al., 2013; Pandey et al., 2016). These categorisations were combined to create eight mutually-exclusive categories of MVPA and ST. Figure 26 gives an overview of the abbreviations used to refer to them.

		Moderate-to-vigorous aerobic physical activity quartile			
		Lowest	**2nd**	**3rd**	**Highest**
Sedentary time	**< 8 hours per day**	Low MVPA/ Low ST	2^{nd} MVPA/ Low ST	3^{rd} MVPA/ Low ST	High MVPA/ Low ST
	≥ 8 hours per day	Low MVPA/ High ST	2^{nd} MVPA/ High ST	3^{rd} MVPA/ High ST	High MVPA/ High ST

Figure 26. Abbreviations used for the Exposure Categories in Study 5. MVPA = moderate-to-vigorous physical activity; ST = sedentary time.

11.2.4 Outcome measures

Data on the four outcome measures of (1) ACM, (2) CVD-related events or mortality, (3) malignant cancer diagnosis or death, and (4) episodes with a principal or non-principal diagnosis of diabetes, came from NHS HS health records. These were already derived with the exception of the specific-cause mortality outcomes for (2) and (3). These were identified by the International Classification of Disease version 10 codes on the health records I00-I99 and C00-C99 respectively. The preliminary analyses do not exclude cases that occur in the first 24 months (a commonly employed technique to reduce the risk of reverse causality) because the follow-up period is too short. The final analyses will do so and projected event rates have been estimated on this basis. Three cases (one in each in the CVD, cancer, and diabetes analyses) were excluded from the relevant analyses because the event occurred on the day of interview. As their follow-up time was zero, they could not be included in the statistical model.

11.2.5 Covariates

All potential confounders for which there was strong theoretical justification were included in the statistical model. This is recommended for exploratory analyses that aim to understand relationships between exposures and outcomes (Shmueli, 2010). This differs from a predictive modelling approach, which selects covariates based on their ability to predict a future outcome and eliminates those without sufficient predictive power (Shmueli, 2010).

The process for covariate selection had five steps. Firstly, potential correlates of MVPA and ST were identified through the most comprehensive systematic reviews of studies involving adults available at the time (Bauman et al., 2012; O'Donoghue et al., 2016) and a Scottish Government Topic Report using data from the SHeS 2012 to investigate the strongest predictors of meeting the MVPA guidelines (Leadbetter et al., 2014). Thirty-four correlates were identified by at least one of these studies (see Appendix 29). Five were excluded as they were either (a) subcomponents of MVPA or ST and so already included as part of the exposure, or (b) a measure of chronic disease and so already included as part of the outcome.

Secondly, SHeS variables were matched to the identified correlates. This was possible for 12 of the correlates; 17 were not measured in the SHeS (see Appendix 29). One of the 12 matches (measures of income, socio-economic position, economic activity status) was divided into the three constituent parts and matching SHeS variables were found for each (making a total of 14). Thirdly, evidence of a plausible association between each of the correlates and the four outcome variables was identified through a non-systematic literature search. Fourthly, five variables were excluded because of high levels of missing data (>5%) in the analysis sample (see Appendix 29). All other variables had <1% missing data. Lastly, variables that had a strong correlation with another were excluded to avoid statistical collinearity. Cross-tabulations were run on pairs of variables that had a strong theoretical basis for correlation (highest education level and deprivation, economic activity status and work status, self-reported general health and limiting long-standing illness). All three pairs showed strong evidence of association. The strength of the association between the covariate and the risk of ACM was tested through Cox proportional hazards models also including the exposure. The variable with the strongest association was kept (see Appendix 29).

The final covariates included in the adjusted models were age, sex, deprivation quintile, economic activity status, self-reported general health, and smoking status. Age was only included in the analyses when not used as a time-scale. The four categories (16-44, 45-64, 65-84, and 85+ years) were chosen based on evidence suggesting that these were ages at which there was a substantial change in risk of chronic disease or mortality (Jousilahti, Vartiainen, Tuomilehto, & Puska, 1999; Office for National Statistics, 2016). The 10-year age-bands conventionally used for health statistics reporting in Scotland would have been too many categories for the sample size, and the difference in risk particularly between youngest age-groups was likely to be small.

11.2.6 Statistical analyses

Cox proportional hazard models (Cox, 1972) were used to assess the relationship between the eight MVPA-ST categories and the four health outcomes, using age as the time-scale. Date of birth was used as the zero value for the time-scale, but as data were only available for birth year, all birthdays were set to 1st January. Two models were run for each outcome (1) unadjusted and (2) adjusting for all covariates. Correlation matrices showed no evidence of strong collinearity between variables in the adjusted models. No evidence of interaction effects were found between any covariates and the exposure measure in the fully-adjusted models. Sensitivity analyses were performed using time-in-study as the time-scale. The projected number of events and corresponding event rates were calculated for the final analyses, based on the upper- and lower-bounds of the 95% CIs for the event rates in the preliminary analysis sample data. The proportional hazards assumptions (that the relative risk between levels of exposure or covariates were constant through the follow-up period) were assessed for each covariate using Schoenfeld residuals and log-log plots. These assumptions were not met but this was expected given the small number of events in the preliminary analysis sample. If these assumptions are not met in the final analyses, alternative specifications of the covariates will be considered.

Analyses were performed in STATA SE version 14.2 (StataCorp, Texas, U.S.) using the svyset commands that accounted for the complex survey design (see Section 4.4.2). The weighting variables were transferred from the interview datasets (see-Appendix 30) by generating a unique identification code for each case dependent on their responses to seven variables. This was necessary as the linked datasets were not provided with the weighting variables that were on the interview datasets. This was possibly because only 84% consent to linkage and the weights do not adjust for this. However, weighting brings the age and sex profile of the preliminary analysis sample much closer to that of the nationally representative weighted interview sample (see Appendix 30). Although the weights are designed for cross-sectional use, there is minimal (<1%) loss to follow-up so this is unlikely to introduce additional attrition bias.

11.2.7 Data management and quality assurance

Data management procedures were agreed and approved in the Confidential Data Release request to ISD (see Appendix 24). Random samples of the code for the preliminary analysis were checked by Dr Paul Kelly. The code included cross-tabulations to ensure the 300 newly derived variables were correct and other examples of ‘sense-checks’.

11.3 Results

11.3.1 Sample characteristics

Twice as many adults were in the HighMVPA/LowST category compared to the Low MVPA/HighST category (20.3% and 9.6% respectively; see Table 9). Those who were more likely to be in the HighMVPA/LowST category were of younger age, male sex, lower levels of deprivation, in education or paid employment, had self-reported good health, and were not current smokers.

11.3.2 Cox proportional hazard models

Figure 27 shows the hazard ratios estimated from the fully-adjusted Cox proportional hazard models for all four health outcomes; a supplementary table in Appendix 31 displays the 95% CIs for the estimates and the unadjusted results. LowMVPA/HighST was the reference category. In the fully-adjusted models, HighMVPA/LowST was associated with a 72% (95% CI: 18-89%) lower risk of ACM, 85% (95% CI: 29-97%) lower risk of CVD-related events or mortality, and 73% (95% CI: 44-89%) lower risk of an episode with a principal or non-principal diagnosis of diabetes. There was also tentative support for a 40% (95% CI: -17%-69%) lower risk malignant cancer diagnosis or death. In all but two comparisons within MVPA quartile, those reporting low ST had a lower risk of the health outcome than those reporting high ST, although the 95% CIs regularly overlapped. Evidence of decreasing risk by MVPA quartile was more apparent in those reporting low ST than high ST. In general, adjustment for covariates attenuated the strength of associations for all outcomes.

11.3.3 Sensitivity analysis, age as a time scale or a covariate

Table 10 presents the Cox proportional hazards model results for the four outcomes when run using age as a time-scale (unadjusted for other covariates), or using time-in-study as a time-scale and with covariate adjustment for age as a covariate. With one exception, the using age as a time-scale lowered the magnitude of the estimate. With two exceptions, it increased the variance of the estimates.

Sixteen of the 28 hazard ratio comparisons had a difference greater than 0.04; five were greater than 0.1.

11.3.4 Projected number of deaths for final analyses

Tables 11 and 12 present the projected unadjusted hazard ratios for the four outcomes in the final analyses (to be undertaken after a mean of seven years of follow-up with the first two years excluded). The lower bound for the event rate was too low to project eight of the 28 hazard ratios. In all situations when an unadjusted hazard ratio could be projected, the confidence intervals (CIs) did not include one. The difference between the hazard ratio estimates was up to 0.27 dependent on whether the upper of lower bound event rate was used (in situations where the lower bound was not zero).

Table 9. Baseline Characteristics of the Sample by Exposure Category

Covariate	MVPA-ST category, % (standard error)								Pearson's design-based X^2- or F-statistic[a]	*p*
	LowMVPA /HighST	LowMVPA /LowST	2ndMVPA /HighST	2ndMVPA /LowST	3rdMVPA /HighST	3rdMVPA /LowST	HighMVPA /HighST	HighMVPA /LowST		
Whole sample	9.6 (0.3)	12.3 (0.4)	7.6 (0.3)	17.1 (0.4)	7.4 (0.3)	18.4 (0.5)	7.3 (0.3)	20.3 (0.5)	2195 (df=1214)	<.001
Age										
16-44	4.2 (0.3)	8.5 (0.5)	7.8 (0.5)	16.0 (0.7)	8.6 (0.5)	20.0 (0.7)	9.6 (0.6)	25.3 (0.9)	45.8 (df=20, 23500)	<.001
45-64	10.0 (0.5)	12.6 (0.7)	7.7 (0.5)	17.7 (0.7)	7.7 (0.5)	18.5 (0.7)	6.7 (0.5)	19.0 (0.7)		
65-84	18.7 (0.9)	18.4 (0.8)	7.2 (0.6)	19.2 (0.8)	4.8 (0.5)	15.7 (0.8)	3.3 (0.4)	12.7 (0.8)		
85+	40.6 (3.7)	34.9 (3.5)	5.3 (1.6)	11.8 (2.4)	1.5 (0.8)	4.1 (1.3)	1.0 (0.7)	0.8 (0.5)		
Sex										
Male	9.7 (0.5)	10.3 (0.5)	7.8 (0.5)	13.6 (0.6)	8.7 (0.5)	16.6 (0.7)	9.3 (0.5)	24.1 (0.8)	30.2 (df=7, 8236)	<.001
Female	9.5 (0.4)	14.0 (0.5)	7.5 (0.4)	20.3 (0.6)	6.3 (0.3)	20.0 (0.6)	5.5 (0.4)	16.9 (0.6)		
Deprivation quintile										
Most deprived	14.6 (0.9)	17.5 (1.0)	7.3 (0.7)	17.4 (1.0)	5.9 (0.7)	17.4 (0.9)	4.8 (0.6)	15.2 (1.1)	8.7 (df=26, 31260)	<.001
2nd	12.3 (0.8)	13.1 (0.8)	9.2 (0.9)	16.4 (1.0)	6.1 (0.6)	19.4 (1.1)	5.9 (0.7)	17.7 (1.1)		
3rd	8.0 (0.7)	13.7 (1.0)	7.9 (0.6)	18.3 (1.0)	7.1 (0.7)	17.9 (0.9)	8.0 (0.7)	19.2 (1.0)		
4th	7.8 (0.6)	9.9 (0.7)	7.3 (0.6)	17.3 (0.8)	8.3 (0.7)	17.4 (0.9)	8.5 (0.7)	23.5 (1.1)		
Least deprived	6.2 (0.6)	8.2 (0.6)	6.4 (0.6)	16.4 (0.9)	9.4 (0.7)	19.7 (1.0)	8.7 (0.7)	25.0 (1.3)		

Economic activity status										
In education	4.1 (0.9)	5.4 (1.1)	6.9 (1.2)	14.2 (1.6)	7.2 (1.3)	23.2 (2.0)	7.6 (1.4)	31.6 (2.5)	40.3 (df=19, 23086)	<.001
In paid employment	4.1 (0.3)	8.5 (0.5)	7.9 (0.4)	17.4 (0.6)	9.6 (0.5)	19.6 (0.6)	9.9 (0.5)	23.1 (0.7)		
Looking for work, looking after home, unable to work, other	17.4 (1.1)	19.1 (1.2)	7.8 (0.8)	15.8 (1.1)	4.9 (0.6)	16.4 (1.1)	3.7 (0.6)	14.8 (1.1)		
Retired	19.5 (0.9)	19.1 (0.8)	7.2 (0.5)	18.5 (0.8)	4.1 (0.4)	15.2 (0.7)	3.1 (0.4)	13.4 (0.8)		
Self-reported general health										
Very good or good	4.7 (0.3)	9.1 (0.4)	6.8 (0.3)	17.7 (0.5)	8.2 (0.4)	20.5 (0.5)	8.7 (0.4)	24.5 (0.7)	119.4 (df=13, 16147)	<.001
Fair	17.1 (0.9)	18.3 (1.0)	9.7 (0.8)	19.0 (1.0)	6.5 (0.6)	14.5 (0.8)	4.4 (0.6)	10.5 (0.8)		
Bad or very bad	38.3 (1.8)	28.5 (1.7)	10.7 (1.1)	8.0 (1.0)	2.1 (0.5)	8.0 (1.0)	0.5 (0.2)	4.0 (0.7)		
Smoking status										
Current smoker	14.3 (0.8)	15.0 (0.8)	8.7 (0.7)	18.0 (0.9)	6.8 (0.7)	17.8 (1.0)	4.6 (0.5)	14.9 (0.9)	12.4 (df=14, 16286)	<.001
Ex-smoker	10.9 (0.6)	12.3 (0.6)	7.6 (0.5)	16.9 (0.8)	7.7 (0.6)	17.7 (0.8)	7.0 (0.5)	19.9 (0.9)		
Never smoked	6.7 (0.4)	11.0 (0.5)	7.2 (0.4)	17.0 (0.6)	7.5 (0.4)	19.0 (0.7)	8.7 (0.5)	22.9 (0.8)		

Note. Percentage of sample (standard error). [a]Pearson's design-based X^2 test for univariate analyses testing goodness-of-fit against a uniform distribution, design-based F-statistic for bivariate analyses testing uniform distributions across categories of MVPA-ST. 'Design-based' indicates the complex sampling is taken into account. MVPA = moderate-to-vigorous physical activity; ST = sedentary time. See Figure 26 for explanation of the MVPA-ST category abbreviations. Maximum missing data in any covariate <1%.

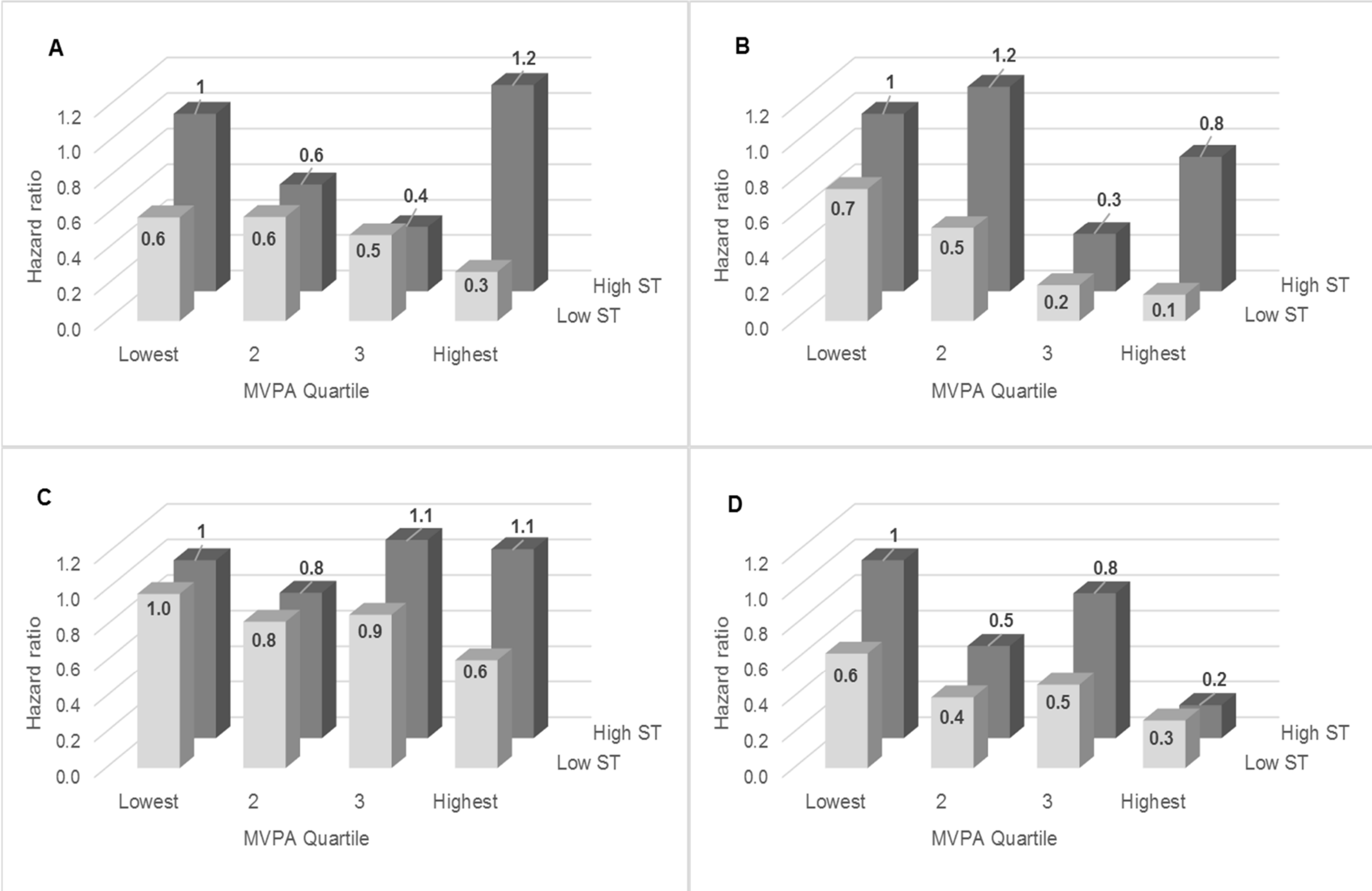

Figure 27. The Joint Effects of Moderate-to-vigorous Physical Activity and Sedentary Time on Four Health Outcomes.

A = all-cause mortality, B = cardiovascular disease-related events or mortality, C = malignant cancer diagnosis or death, D = episodes with a principal or non-principal diagnosis of diabetes. MVPA = moderate-to-vigorous physical activity; ST = sedentary time. MVPA quartile values: 0-<1.6, 1.6-<12.8, 12.8-<38.4, and ≥38.4 MET-hours per week. Confidence intervals are presented in Appendix 31.

Table 10. Sensitivity Analysis on the Choice of Time-scale for the Cox Proportional Hazards Models

Outcome, and exposure category	Events/n (Model 1[a])	Age as time-scale		Time-in-study as time-scale, with age as a covariate	
		HR	95% CI[b]	HR	95% CI[b]
All-cause mortality					
LowMVPA/HighST	65/1089	1		1	
LowMVPA/LowST	28/1390	0.44	0.28, 0.69	0.42	0.27, 0.66
2ndMVPA/HighST	7/863	0.33	0.15, 0.72	0.27	0.12, 0.59
2ndMVPA/LowST	14/1942	0.27	0.16, 0.47	0.21	0.12, 0.36
3rdMVPA/HighST	2/841	0.15	0.06, 0.41	0.11	0.04, 0.30
3rdMVPA/LowST	9/2083	0.20	0.10, 0.39	0.16	0.08, 0.30
HighMVPA/HighST	4/823	0.38	0.15, 0.98	0.25	0.10, 0.66
HighMVPA/LowST	3/2301	0.09	0.04, 0.24	0.06	0.03, 0.17
Cardiovascular disease-related events or mortality					
LowMVPA/HighST	26/1088	1		1	
LowMVPA/LowST	15/1390	0.66	0.35, 1.24	0.58	0.31, 1.09
2ndMVPA/HighST	9/863	0.87	0.41, 1.85	0.75	0.35, 1.57
2ndMVPA/LowST	9/1942	0.36	0.17, 0.79	0.29	0.13, 0.64
3rdMVPA/HighST	2/841	0.23	0.03, 1.63	0.17	0.02, 1.22
3rdMVPA/LowST	3/2083	0.14	0.03, 0.56	0.11	0.03, 0.44
HighMVPA/HighST	3/823	0.49	0.09, 2.54	0.32	0.06, 1.57
HighMVPA/LowST	2/2301	0.09	0.02, 0.41	0.06	0.01, 0.30
Malignant cancer diagnosis or death					
LowMVPA/HighST	44/1087	1		1	
LowMVPA/LowST	41/1390	0.89	0.57, 1.40	0.90	0.57, 1.41
2ndMVPA/HighST	14/863	0.71	0.38, 1.33	0.66	0.35, 1.24
2ndMVPA/LowST	30/1942	0.65	0.40, 1.06	0.59	0.36, 0.96
3rdMVPA/HighST	13/841	0.93	0.47, 1.82	0.78	0.40, 1.52
3rdMVPA/LowST	29/2083	0.68	0.41, 1.13	0.62	0.37, 1.03
HighMVPA/HighST	9/823	0.86	0.30, 2.45	0.68	0.25, 1.89
HighMVPA/LowST	18/2301	0.48	0.26, 0.89	0.40	0.22, 0.73

Events with a principle or non-principle diagnosis of diabetes					
LowMVPA/HighST	56/1088	1		1	
LowMVPA/LowST	30/1390	0.50	0.31, 0.78	0.49	0.31, 0.79
2ndMVPA/HighST	10/863	0.34	0.18, 0.65	0.34	0.18, 0.63
2ndMVPA/LowST	14/1942	0.19	0.11, 0.35	0.19	0.11, 0.34
3rdMVPA/HighST	9/841	0.38	0.16, 0.91	0.36	0.15, 0.87
3rdMVPA/LowST	14/2083	0.21	0.11, 0.38	0.20	0.11, 0.36
HighMVPA/HighST	1/823	0.07	0.02, 0.32	0.07	0.02, 0.29
HighMVPA/LowST	6/2301	0.10	0.05, 0.23	0.09	0.04, 0.21

Note. Weighted n = 11,332-11,334 depending on cases with event on day of interview. CI = confidence interval; HR = hazard ratio; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. See Figure 26 for explanation of the MVPA-ST category abbreviations. [a]95% CIs calculated using Taylor-Series linearisation variance estimation techniques.

Table 11. Event Rates Calculated from the Preliminary Analysis Sample

Outcome, and exposure category	Weighted n	Weighted person-years of follow-up	Observed number of events	95% CI[a]	Event rate (event/person-year)	
					Using lower bound CI[b]	Using upper bound CI[b]
All-cause mortality						
LowMVPA/HighST	1089	1624	65	48, 81	0.03	0.05
LowMVPA/LowST	1390	2047	28	17, 38	0.01	0.02
2ndMVPA/HighST	863	1346	7	2, 13	0.00	0.01
2ndMVPA/LowST	1942	2939	14	7, 21	0.00	0.01
3rdMVPA/HighST	841	1255	2	0, 4	0.00	0.00
3rdMVPA/LowST	2083	3172	9	4, 15	0.00	0.00
HighMVPA/HighST	823	1195	4	0, 8	0.00	0.01
HighMVPA/LowST	2301	3444	3	0, 6	0.00	0.00
Total	11332	17022	132	78, 186		
Cardiovascular disease-related events or mortality						
LowMVPA/HighST	1089	1665	26	16, 36	0.01	0.02
LowMVPA/LowST	1390	2055	15	8, 23	0.00	0.01
2ndMVPA/HighST	863	1346	9	3, 15	0.00	0.01
2ndMVPA/LowST	1942	2943	9	3, 14	0.00	0.00
3rdMVPA/HighST	841	1257	2	0, 5	0.00	0.00
3rdMVPA/LowST	2083	3181	3	0, 7	0.00	0.00
HighMVPA/HighST	823	1196	3	0, 6	0.00	0.01
HighMVPA/LowST	2301	3445	2	0, 4	0.00	0.00
Total	11331	17087	69	30, 110		

Malignant cancer diagnosis or death						
LowMVPA/HighST	1087	1646	44	31, 58	0.02	0.04
LowMVPA/LowST	1390	2027	41	27, 54	0.01	0.03
2ndMVPA/HighST	863	1340	14	6, 22	0.00	0.02
2ndMVPA/LowST	1942	2917	30	19, 41	0.01	0.01
3rdMVPA/HighST	841	1247	13	5, 21	0.00	0.02
3rdMVPA/LowST	2083	3151	29	18, 41	0.01	0.01
HighMVPA/HighST	823	1194	9	0, 19	0.00	0.02
HighMVPA/LowST	2301	3428	18	9, 26	0.00	0.01
Total	11330	16948	198	115, 282		
Events with a principle or non-principle diagnosis of diabetes						
LowMVPA/HighST	1088	1635	56	40, 71	0.02	0.04
LowMVPA/LowST	1390	2043	30	19, 42	0.01	0.02
2ndMVPA/HighST	863	1348	10	5, 16	0.00	0.01
2ndMVPA/LowST	1942	2954	14	7, 22	0.00	0.01
3rdMVPA/HighST	841	1256	9	2, 16	0.00	0.01
3rdMVPA/LowST	2083	3184	14	7, 21	0.00	0.01
HighMVPA/HighST	823	1210	1	0, 4	0.00	0.00
HighMVPA/LowST	2301	3468	6	1, 11	0.00	0.00
Total	11331	17098	140	81, 203		

Note. CI = confidence interval; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. See Figure 26 for explanation of the MVPA-ST category abbreviations. [a]Lower bound rounded up zero when true value negative; [b]Calculated as lower/upper bound of events divided by person years.

Table 12. Projected Hazard Ratios for the Final Analyses

Outcome, and exposure category	Expected weighted n[a]	Expected weighted person-years of follow-up[b]	Expected number of events[c]		Expected event rate (events/person-year)		Expected hazard ratios			
			Lower bound	Upper bound	Lower bound	Upper bound	HR	95% CI[d]	HR	95% CI[d]
All-cause mortality										
LowMVPA/HighST	1281	8969	189	319	0.02	0.04	1		1	
LowMVPA/LowST	1635	11448	68	152	0.01	0.01	0.27	0.21, 0.36	0.36	0.29, 0.44
2ndMVPA/HighST	1015	7108	8	49	<.01	0.01	0.05	0.02, 0.10	0.18	0.13, 0.25
2ndMVPA/LowST	2285	15994	27	82	<.01	0.01	0.08	0.05, 0.12	0.13	0.10, 0.17
3rdMVPA/HighST	989	6925	0	16	0.00	0.00		N/A	0.06	0.04, 0.10
3rdMVPA/LowST	2451	17155	15	58	<.01	0.00	0.04	0.02, 0.07	0.09	0.07, 0.12
HighMVPA/HighST	969	6781	0	32	0.00	0.00		N/A	0.13	0.09, 0.18
HighMVPA/LowST	2707	18950	0	24	0.00	0.00		N/A	0.03	0.02, 0.05
Total	13333	93331	307	732						
Cardiovascular disease-related events or mortality										
LowMVPA/HighST	1280	8961	63	142	0.01	0.02	1		1	
LowMVPA/LowST	1635	11448	32	92	<.01	0.01	0.39	0.26, 0.60	0.50	0.36, 0.69
2ndMVPA/HighST	1015	7108	11	57	<.01	0.01	0.22	0.12, 0.42	0.49	0.35, 0.71
2ndMVPA/LowST	2285	15994	12	54	<.01	<.01	0.10	0.05, 0.19	0.21	0.15, 0.30
3rdMVPA/HighST	989	6925	0	20	0.00	<.01		N/A	0.18	0.11, 0.29
3rdMVPA/LowST	2451	17155	0	27	0.00	<.01		N/A	0.10	0.06, 0.15
HighMVPA/HighST	969	6781	0	24	0.00	<.01		N/A	0.22	0.14, 0.35
HighMVPA/LowST	2707	18950	0	16	0.00	<.01		N/A	0.05	0.03, 0.09
Total	13332	93323	118	432						

Malignant cancer diagnosis or death										
LowMVPA/HighST	1279	8952	122	229	0.01	0.03	1		1	
LowMVPA/LowST	1635	11448	108	216	0.01	0.02	0.69	0.53, 0.89	0.73	0.58, 0.91
2ndMVPA/HighST	1015	7108	23	83	<.01	0.01	0.23	0.15, 0.36	0.44	0.34, 0.59
2ndMVPA/LowST	2285	15994	74	159	<.01	0.01	0.33	0.25, 0.44	0.38	0.30, 0.48
3rdMVPA/HighST	989	6925	20	83	<.01	0.01	0.20	0.13, 0.33	0.46	0.34, 0.60
3rdMVPA/LowST	2451	17155	70	158	<.01	0.01	0.29	0.22, 0.39	0.35	0.28, 0.44
HighMVPA/HighST	969	6781	0	77	0.00	0.01		N/A	0.43	0.33, 0.58
HighMVPA/LowST	2707	18950	35	102	<.01	0.01	0.13	0.09, 0.19	0.20	0.16, 0.26
Total	13331	93315	451	1107						
Events with a principle or non-principle diagnosis of diabetes										
LowMVPA/HighST	1280	8961	158	280	0.02	0.03	1		1	
LowMVPA/LowST	1635	11448	76	168	0.01	0.02	0.37	0.36, 0.56	0.45	0.36, 0.56
2ndMVPA/HighST	1015	7108	19	60	<.01	0.01	0.15	0.19, 0.35	0.26	0.19, 0.35
2ndMVPA/LowST	2285	15994	27	86	<.01	0.01	0.09	0.12, 0.21	0.16	0.12, 0.21
3rdMVPA/HighST	989	6925	8	63	<.01	0.01	0.06	0.21, 0.37	0.28	0.21, 0.37
3rdMVPA/LowST	2451	17155	27	81	<.01	<.01	0.09	0.11, 0.19	0.14	0.11, 0.19
HighMVPA/HighST	969	6781	0	16	<.01	<.01	0.00	0.04, 0.12	0.07	0.04, 0.12
HighMVPA/LowST	2707	18950	4	43	<.01	<.01	0.01	0.05, 0.10	0.07	0.05, 0.10
Total	13332	93323	319	797						

Note. CI = confidence interval; HR = hazard ratio; MVPA = moderate-to-vigorous physical activity; N/A = not applicable; ST = sedentary time. See Figure 26 for explanation of the MVPA-ST category abbreviations. [a]Calculated by scaling up the proportion in each exposure category in the preliminary analysis sample to the projected final analysis sample size as shown in Figure 24; [b]Assuming mean 7 years of follow-up; [c]Projected using the lower/upper bound event rates from Table 11, removing events in first 24 months of follow-up based on the same event rate; [d]Calculated without taking complex survey design into account (the four-year sample will be unclustered by disproportionate stratification may have an effect).

11.4 Discussion

11.4.1 Principal findings

The preliminary analyses suggest that the HighMVPA/LowST category had a reduced risk of ACM, CVD-related events or mortality, and episodes with a principal or non-principal diagnosis of diabetes compared with those in the LowMVPA/HighST category. The estimated risk reductions were substantial (40-85%) although the 95% CIs were wide (as would be expected with the event numbers in the short follow-up period). There was tentative evidence that the risk of malignant cancer diagnosis or death was also reduced. However, given the 95% CI crossed one, there is still uncertainty as to whether there is no association or even potentially a harmful one. There were some potentially meaningful differences in the unadjusted hazard ratios when age or time-in-study was used as a time-scale, the former attenuated the magnitude of the effect.

The rest of this chapter focuses on the implications of these results for the final analyses that will be run in 2022-2023 after the data from an average of seven years of follow-up is available. Some policy implications will be suggested although it is important not to over-interpret the preliminary results.

11.4.2 Implications for planned study

The projected unadjusted hazard ratios and associated CIs provide an indication that the final analyses should be sufficiently powered to detect differences between exposure categories if they exist. In all situations when an unadjusted hazard ratio could be projected, all MVPA-ST combinations had a protective effect when compared to the LowMVPA/HighST group. The preliminary analyses indicate that adjustment for covariates is likely to attenuate or even eliminate these associations, and may also increase the uncertainty around the estimates. However, the unadjusted effect is strong and the projected CIs are relatively narrow so it is realistic to expect any true differences will be detected.

It is also plausible to expect the event rates to increase as the sample ages. This should not introduce any bias that would change the magnitude of the estimates as using age as a time-scale or as a covariate should adjust for differential age profiles in exposure groups. However, it is questionnable whether the latter is appropriate over a 6-9 year follow-up period. In the present study, when age was included as a covariate, I used the categories of 16-44, 45-64, 65-84, and 85+ years. One could argue whether this categorisation would adequately adjust for the age-related changes risk of mortality or morbidity over a 9-year follow-up period. For example, respondents in the 65-84 year category may have a similar risk at baseline, but the change in risk in the subsequent nine years may differ. Respondents that were 65 and 80 at interview will be 89 and 74 years old by the end of the follow-up period. As the age-related risk of mortality increases sharply around the age of 85 (Office for National Statistics, 2016), adjusting for age in this way may not fully account for the change in risk.

It is also important to acknowledge that that high effect size estimates in both the preliminary and projected final analyses results are potentially affected by reverse causality. Underlying health conditions at baseline could have caused the respondent to be in the LowMVPA/HighST category, it could also increase the risk of any of the four outcomes. The final analyses will remove cases with an event in first two years to account for this, but it may mean the extrapolations are an overestimate of the difference in event rates. Another consideration that could further reduce the risk of reverse causality bias in the final analyses is to exclude those that self-report a chronic condition at baseline. This was not done in the preliminary analyses due to the low number of events, which is the key factor in determining the certainty associated with the estimate.

Given that this bias could potentially influence the event rate in the LowMVPA/HighST category more than others, one could also mitigate its influence by changing the reference category. The reason for the choice in the preliminary analyses was because including the category with the highest number of events in every comparison reduces the width of the CIs. When HighMVPA/LowST was used as the referent category (results not shown), only the comparison where the 95% CIs did not cross one was for LowMVPA/HighST. It is also worth noting that the extrapolated event rates were not sufficient to detect differences when using the HighMVPA/LowST reference category. This may become even more important if interaction effects are detected (with such few events in the preliminary analyses they were likely under-powered). This would require stratified analyses.

The results of the sensitivity analyses suggest that the magnitude and variance of the estimated hazard ratios may be affected by the choice of time-scale. Undertaking such sensitivity analyses are important as the choice of time-scale is inconsistent in the current literature and the effect on the estimates is unknown. It is important that PA and SB epidemiologists stay on top of statistical developments (other examples include the utility of *p* values and increasing advocacy not to use them) because this provides credibility to our work. Although the fine nuances may not be understood by those making policy decisions (and do not need to be), opening ourselves up to unnecessary criticism does not generate trust. Also, if studies on PA or ST are to be included in combined NCD risk factor analyses then it is important that the appropriate methods are used. Previously, MVPA has been excluded from such studies because estimates of population burden did not sufficiently account for other risk factors (Kontis et al., 2014).

11.4.3 Potential implications for policy-makers

The preliminary results suggest that the combination of HighMVPA/LowST considerably lowers the risk of ill health compared to LowMVPA/HighST. About 10% of the sample (nationally representative of adults in private households in Scotland in 2012-14) reported LowMVPA/HighST. The final analyses may be able to shed light on whether changing MVPA or ST levels would have the greatest benefits to health. Although it is likely that changing both is optimal, certain changes might be easier or most cost-effective from a policy and/or practice point of view.

Figure 28 shows the behaviours that could remain or change when converting from a LowMVPA/HighST to a HighMVPA/LowST profile. The letters A, B, and C reflect the potential reallocation of time: ‘A’ shows the movement of ST to light PA, ‘B’ shows the movement of ST to MVPA, and ‘C’ shows the movement of light PA to MVPA. Spence, Rhodes, and Carson (2017) have suggested that ‘B’ could be a challenging intervention to undertake. Their justification for this is because it would involve a change in behaviour rather than just a change in posture. Addressing ‘A’ or ‘C’ could potentially be easier as individuals could continue with their behaviour (e.g. watching TV or walking slowly) but could undertake it in a different manner (e.g. standing up or walking briskly, respectively). A further justification for focussing on ‘A’ is that efforts to increase MVPA (whether through interventions targeting ‘B’ or ‘C’) have not changed prevalence figures in Scotland since 2008 (Currie, 2017). One could argue that simply maintaining levels is a success given the ageing population, but it is still falling short of the agreed 2025 target (WHO, 2013a).

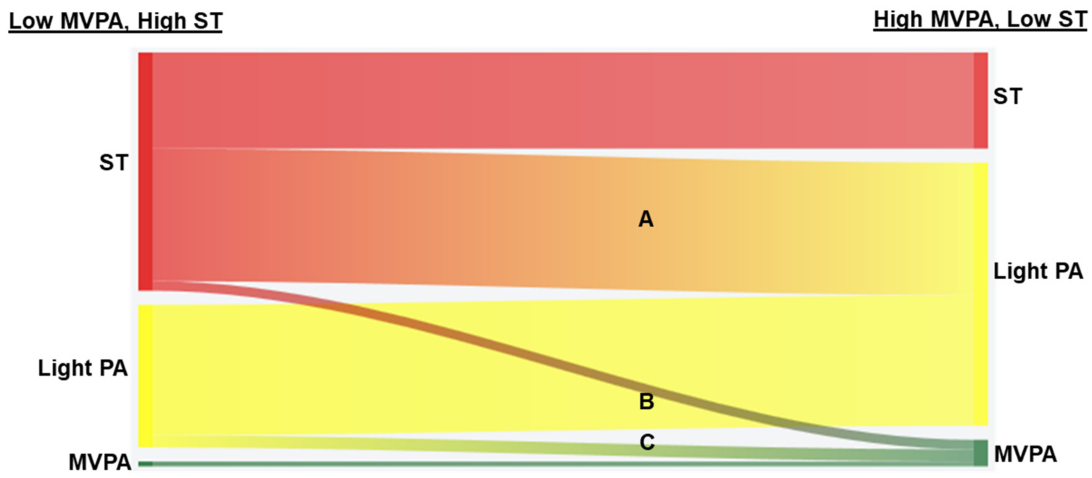

Figure 28. Converting from LowMVPA/HighST to HighMVPA/LowST Profile.

PA = physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. A to E reflect behaviours that could remain or change when converting from a LowMVPA/HighST to a HighMVPA/LowST profile. A: ST changes to Light PA; B: ST changes to MVPA; C Light PA changes to MVPA.

11.4.4 Strengths and limitations

A major strength of the final analyses is that it will use the optimal dataset to investigate this research question at the earliest possible opportunity, whilst incorporating measures to minimise the risk of reverse causality. This provides some degree of future-proofing. Rosenberg et al. (2015) identified only one large cohort study currently using inclinometers to assess ST. Therefore, it is probable that the results of the final analyses will make a useful contribution to the literature at the time as it will be some time before inclinometer data supersede this work. As Study 4 demonstrated, the results of the SHeS have strong internal and external validity which distinguishes it from many other large cohort studies such as BioBank (Lightfoot & Dibben, 2013). Furthermore, Scotland can justifiably claim to have one of the best health data linkage systems in the world. All health systems in Scotland use a unique patient identifier helping records from different hospitals and sectors to be gathered together and easily matched to survey respondents (Sullivan, 2014). This is evidenced by the 99% match rate in the present data. This improves study quality as it reduces the risk of introducing bias when cases either fail to be matched or are mismatched (Public Health Research Data Forum, 2015). Scotland also has very low emigration rates which should limit loss during the follow-up period (another potential source of bias). The final analyses will also benefit from the increased scrutiny placed on the methods during these preliminary analyses. This chapter has described how analytical decisions can influence the validity of the results. It emphasises the importance of understanding the statistical models and the relationships between the variables of interest, rather than just following 'rules'.

There are a number of limitations to the study that should be acknowledged. Firstly, Study 4 found that the 2012-15 SHeS ST measurement instrument was better for ranking individuals by ST rather than estimating total ST. This was mitigated by the categorisation of the data. However, it is possible that 'noise' introduced through the imprecise measurement methods attenuated the magnitude of the true differences between groups. Secondly, MVPA and ST were only measured at interview and it is possible that respondents changed their behaviours over the course of the follow-up period, diluting the results. Obtaining another measure of exposure during the follow-up period would be preferable but not feasible given resource constraints.

Also, although there was good justification for choosing 8 hours as a category boundary for ST (see Section 11.2.2), it may not have given the most appropriate comparisons. The distribution of total ST in the sample was approximately normal with a mean of 6.7 hours. Therefore, the majority of the sample were clustered at the top end of the low ST and the bottom end of the high ST categories. In reality, there may not be a great difference in risk between these groups. It also means that at an individual level, those with similar ST profiles (e.g. 7.8 and 8.2 hours per day) are categorised differently. This may not be the most appropriate way of reflecting the associated risk of their ST. Splitting ST into three or four categories would mitigate this; if the number of events are sufficient in the final analyses then this could be considered. However, unless one treats ST as a continuous variable (which presents a set of statistical decisions that are beyond the scope of this thesis to describe), one has to select some category boundaries.

It is also possible that there are other confounding factors not included in the fully-adjusted model which could have introduced bias. One example may be alcohol consumption which was not identified through the systematic search process. It may also be important to consider whether occupational activity can be adjusted for, as it was not included in the exposure measure. Some variables such as BMI were excluded from the fully-adjusted models because of high rates of missing data in the variable. Although the exact relationship between MVPA, ST and risk of weight gain are yet to be elucidated fully (Biddle et al., 2017; Wareham, van Sluijs, & Ekelund, 2005), there it is likely that an optimal model would include some measure to protect against confounding.

Another potential source of bias is that the assumed relationships between the identified covariates and the exposure and outcome measures are incorrect and that collider or over-adjustment biases could be introduced. It would be prudent to reassess the evidence for these relationships when undertaking the final analyses; constructing a causal diagram may be helpful.

I took the decision to exclude the variables with high levels of missing data from the adjusted analyses because the number of events was already low in the preliminary analysis sample and further exclusion of respondents would have increased the CIs considerably. The final analyses should have sufficient power to be able to include these variables (and remove the individuals without complete data) from the fully-adjusted models. However, whether this is the most appropriate way to deal with potential biases will depend on whether the data are missing at random, and so this should be considered.

Finally, some have questioned whether it is appropriate to consider cancer mortality as one outcome when the associations with MVPA and ST are known to be type-specific (Grace et al., 2017). This may be a reason why weaker associations were seen and projected compared with other outcomes. The health records do provide some site-specific information and so if the event rates are sufficient to provide robust estimates then separating the outcomes is something the final analyses could consider.

11.5 Future research

As has been described, the protocol and analysis code developed through Study 5 will be used in 2022-2023 to answer the research questions stated. An average seven-year follow-up period should provide an appropriate level of certainty to the estimates, but remain current to the academic and policy debate. However, there is the flexibility in the data to adapt to most eventualities. For example if a quantified ST recommendation was introduced or there was a change in the time and/or frequency of MVPA recommended, the exposure categories could be changed to maximise policy relevance.

11.6 Conclusions

These preliminary analyses suggest that the combination of high MVPA and low ST are strongly protective against the risk of ACM, CVD-related events or mortality, and episodes with a principal or non-principal diagnosis of diabetes amongst adults in Scotland. The choice of time-scale for the Cox proportional hazard models is important to consider as it may affect the magnitude and certainty of the estimates. Based on projections, the final analyses should be able to provide greater certainty to these conclusions and have the potential to include further measures to reduce bias.

Chapter 12: Thesis Discussion

This chapter discusses the thesis as a whole. It summarises the main findings in relation to the aims and objectives, discusses the over-arching themes, the strengths and limitations of the overall PhD programme of work, and speculates on future directions for this area of work.

12.1 Thesis Overview

This thesis set out five objectives (see Section 5.1 and 10.2):

1. investigate the domain-specific contributions to total MVPA amongst adults in Scotland;
2. investigate the prevalence of MSA and BCA participation amongst adults in Scotland;
3. investigate the levels of total ST amongst adults in Scotland; and
4. review the existing evidence relating to whether the 2012-15 SHeS method for estimating PA and ST produces valid and reliable results; and
5. investigate the effects of ST and MVPA on health outcomes amongst adults in Scotland.

Studies 1-5 met these objectives by finding that amongst adults in Scotland (1) sport was a minority contributor to total MVPA, regardless of sex, age, or activity status (never more than 20%), (2) compliance with the MSA recommendation was approximately half that of the MVPA recommendation (31% of men and 24% of women), and compliance with the BCA recommendation amongst adults over 65 years was very low (19% of older men and 12% of older women), (3) middle-aged adults in work reported a comparable amount of weekday ST to adults over 75 years (between 7 and 8 hours per day), (4) the results of Studies 1-3 were valid and reliable so long as certain caveats were taken into account in their interpretation, and (5) the combination of high levels of MVPA and low levels of ST were strongly associated with increased risk of ACM, CVD-related events or mortality, and an episode with a principal or non-principal diagnosis of diabetes. The findings relating to the fifth objective are based on preliminary analyses; projected results suggest that the final analyses will confirm these findings with greater certainty using the methods and analysis code I have developed.

There is evidence that this work has already informed Scottish PA policy and surveillance. Briefly, Study 1 was a useful reference to show the importance of non-sporting PA amongst adults in Scotland. This supported a policy environment conducive to cross-sectoral policies like the recent increase in the active travel budget (The Scottish Government, 2017a). Studies 2 and 3 have been instrumental in proposals to include indicators for MSA, BCA, and ST on the ASOF. The combined work of Studies 1-3 and Study 4 have led to my involvement as an advisor on future developments to the SHeS PA and ST measurement instrument and on the surveillance of MSA and BCA through the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance. Study 5 has the potential to inform a policy that integrates both MVPA and ST in Scotland. More details as to how each study has made a novel contribution to knowledge and has informed policy and surveillance are in Table 13.

Table 13. Overview of Studies 1-5 in Relation to the Thesis Aim

Study	Original contribution to knowledge	Informed policy	Informed surveillance
Study 1: Domains of MVPA	Used Scottish-specific data to investigate absolute and relative contributions of domains to total MVPA, analysed at an individual-level[a]. Investigated statistical differences by sex, stratified by age and activity status. Published in a peer-reviewed publication.	Contributing to changing attitudes amongst policy-makers about the contribution of sport to total MVPA.	Concerns with estimation of domain of occupational MVPA confirmed need to address validity and reliability in Study 4. Together, Studies 1 and 4 were influential in the PAHRC response to the SHeS PA and ST questionnaire consultation.
Study 2: MSA and BCA	Used Scottish-specific data to investigate statistical differences by age and sex in MSA and BCA recommendation compliance and participation in specific activities. Published in a peer-reviewed publication.	Directly contributed to proposals to include MSA and BCA indicators on the ASOF.	Key text influencing the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance to consider surveillance issues in detail. Identified and helped to correct an error in archived datasets on MSA and BCA recommendation compliance.
Study 3: ST	Used Scottish-specific data to investigate statistical differences by age and sex in the total ST of adults (including ST at work). Separate weekday and weekend day analyses; weekday analyses also stratified by employment status. Investigated statistical differences by age and sex in the relative contributions of categories of behaviours. Published in a peer-reviewed publication.	Contributed to proposals to include an ST indicator on the ASOF.	Facilitated communication between Glasgow Caledonian University and those involved in surveillance regarding proposed changes to the SHeS ST questions. Ongoing discussions with the Scottish Government to include ST at work in estimates for total weekday ST in the Annual Reports.

Study 4: Validity and reliability	The first ever review of the exisiting validity and reliability evidence for the 2012-15 SHeS PA and ST method. First use of the Edinburgh Framework as a practical tool to guide an evidence review.	N/A	Heavily influential in the PAHRC repose to the 2016 SHeS consultation on the PA and ST questionnaire. Personally invited to advise ScotCen on future developments of questionnaire. Together with Study 2, it has been influential in the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance's considerations of surveillance issues.
Study 5: Joint effects of MVPA and sedentary time	First assessment of the joint effects of MVPA and total ST using nationally representative Scottish-specific data. Considered the effect on the results of time-scale choice in the Cox proportional hazards models.	Has the potential to inform integrated policy around the promotion of MVPA and reduction of ST.	N/A

Note. ASOF = Active Scotland Outcomes Framework; BCA = balance and co-ordination activity; CMO = Chief Medical Officer; MSA = muscle strengthening activity; MVPA = moderate-to-vigorous physical activity; PAHRC = Physical Activity for Health Research Centre; SHeS = Scottish Health Survey; ST = sedentary time. [a]Individual level analyses involved calculating the relative contributions of the domains at an individual level before calculating group level averages.

12.2 Discussion of Main Themes

12.2.1 The interactions between academic research, policy, surveillance, and practice

In Section 5.2, I presented a simplistic cyclical model to represent the interactions between academic research, policy and surveillance, and practice (Figure 8). My experiences undertaking this PhD programme of work have led me to refine this model (see Figure 29).

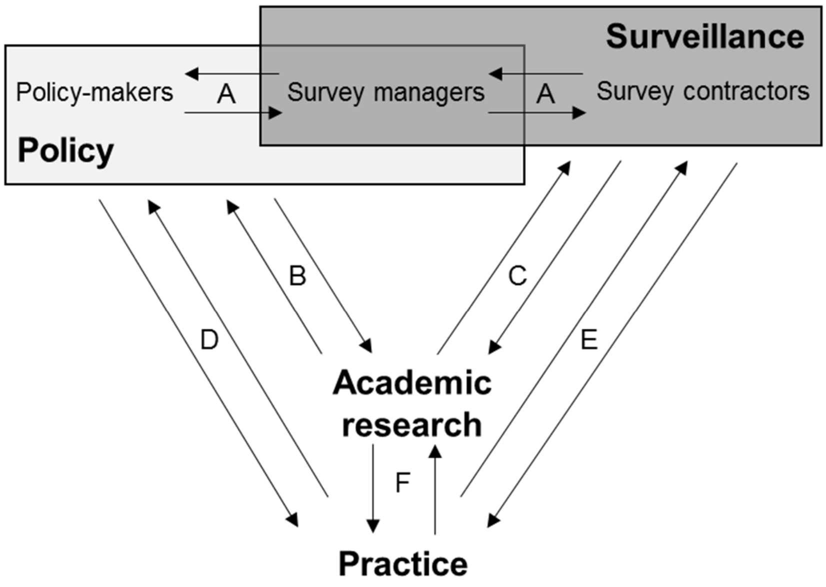

Figure 29. A Schematic Overview of the Interactions Between Academic Research, Policy, Surveillance, and Practice as Experienced During this PhD.
The following letters represent the interactions between A: policy-makers, survey managers, and survey contractors; B: academic research and policy; C: academic research and surveillance; D: policy and practice; E: surveillance and practice; F: academic research and practice.

The main difference between Figures 8 and 28 is the partial separation of policy and surveillance. Whilst surveillance falls under the definition of policy presented in Section 2.5, I argue that it is helpful to consider them as distinct areas. Most large surveys will be contracted out to research companies because of the person-power required. In the case of the SHeS, this is ScotCen. Although the

Scottish Government manage the survey, ScotCen play a large role in questionnaire design and making strategic decisions. Also, within the Scottish Government, the survey manager is separate from those involved in PA policy. The arrows labelled ‘A’ in Figure 29 reflect communication between these parties, processes that should not be assumed. This had implications for my communications as an academic researcher with policy and surveillance. These interactions (‘B’ and ‘C’ on Figure 29) were separate from each other, involving different people and requiring different approaches based on their area of expertise and priorities. For example, the proposals to add indicators to the ASOF originated from a lay summary of Study 2 sent to the head of PA policy in the Scottish Government. By contrast, the interactions with survey contractors and manager around the inclusion of ST at work in the estimates for total ST included lines of code for use in statistical software. Different findings were relevant for different groups and required different methods of communication. Understanding these differences was valuable because I was able to share my work more appropriately.

These reflections may be of interest to other academic researchers in our field as both the Bangkok and Toronto Charters highlighted the importance of informing surveillance within the overall PA promotion agenda (Bull et al., 2010; ISPAH, 2016). Academic researchers can usefully contribute their knowledge on measurement instruments’ abilities to produce valid and reliable results, and their awareness of global harmonisation efforts and likely future measurement developments (Fulton et al., 2016). The motivations are not all altruistic; analyses of national surveillance data have been critical in advancing the field of PA and ST epidemiology (e.g. Dankel et al., 2016b; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Stamatakis et al., 2011). It would be almost unfeasible to collect such volumes of data in such a rigorous manner given time and funding constraints on academic researchers. Therefore, efforts to improve these surveys can be directly beneficial to academic researchers.

The interactions between academic research and policy (reflected by ‘B’ on Figure 29) have presented some scientific and ethical dilemmas during the course of the PhD. One reoccurring theme was around how to communicate the latest evidence in an emerging field, for example, around the dose-response relationship between ST and health outcomes. This was not unique to my experiences: Brownson, Royer, et al. (2006), Giles-Corti et al. (2015), and Whitty (2015) have all noted that academic researchers and policy-makers work on different time-scales. The time academic researchers would like to gather sufficient evidence to support a policy is different to those whose managers work to election cycles. There is no definitive answer as to when the evidence is ‘sufficient’ (Cairney & Oliver, 2017), and so deciding when and/or where to make compromises is a dilemma academic researchers face (Evans, 2003). To help me find the right balance, I sought advice from other experienced academic researchers on this decision (my supervisors and others from Glasgow Caledonian University). The consensus was that it was worth seizing the opportunity to promote these recommendations, even if future changes are required. Although we may not have sufficiently valid and reliable data to develop a quantified ST recommendation at present, we do know the direction of relationships. Therefore the policy promotion efforts undertaken as part of this thesis can be justified.

Communicating this nuanced message to policy-makers was further complicated by the media attention given to some of the findings. Getting an issue on the public agenda is a known way to raise awareness amongst policy-makers (Bauman, Nelson, Pratt, Matsudo, & Schoeppe, 2006; Brownson, Kreuter, Arrington, & True, 2006). Therefore opportunities to discuss the work with the media were taken up. I tried to navigate this issue by remaining faithful to the scientific interpretation of evidence and avoiding being manipulative or hyperbolic (Cairney & Oliver, 2017; K. Smith & Stewart, 2017). However, some aspects were out of my control. For example, some the media coverage of Study 3 focussed on the fact that 45-54 year old men reported the highest levels of ST out of all the age groups. This was despite the fact that I had decided that the better interpretation of the data was not to single out this group, but focus on the trend across the middle ages. These experiences have made me more aware of the competing tensions of informing policy with academic research and I believe that will help me make appropriate decisions in the future.

Another point to consider is whether undertaking the research to fill the knowledge gaps would have been sufficient to inform policy and surveillance without the additional knowledge exchange activities. My personal view is it would not; this is supported by the experiences of others. Brownson, Kreuter, et al. (2006) and Giles-Corti et al. (2015) describe the importance of a personal relationship with policy-makers to increase the likelihood of academic research uptake. Also, a study in Australia recently concluded that it was the dissemination activities undertaken by researchers that ultimately determined a study's influence on policy (Newson et al., 2015). Impact beyond the world of academia is increasingly important to funders and for the Research Excellence Framework (Higher Education Funding Council for England, 2016; Research Councils U.K., 2014), and so these efforts are worthwhile on many levels.

Examples of the interactions between policy and practice, and between academic research and practice are numerous (D and F on Figure 29), although interactions between surveillance and practice are less obvious (E on Figure 29). Although all interactions with practice were beyond the scope of this thesis, I became aware of how practice could interact directly with surveillance. For example, a local authority introduced specific activity classes for older adults in part due to the prevalence figures highlighting the need in this age group. I was also aware of the SHeS contractors considering views from local authorities that wanted to compare their local survey results with the SHeS.

One could level valid criticism at the decision not to focus on these interactions; it is well known that finding population-level solutions to low MVPA levels is where the evidence is weakest (ISPAH, 2016). It is also one of the most challenging areas in our field (Rütten, Abu-Omar, Gelius, & Schow, 2013). In defence, I argue that the areas of MSA, BCA, and ST are less well established and that they need to be on the policy agenda before large scale interventions can be designed and/or implemented to address the concerning average levels of adults in Scotland highlighted in this thesis. If related to the Behavioural Epidemiology Framework (Sallis et al., 2000), the present work would be classified as Phases 1-3 (establishing the links between behaviours and health, developing/refining methods for measurement, and describing the demographic correlates). Sallis et al. (2000) suggest that this work should occur prior to the evaluation of interventions and their implementation. However, I have taken actions to support and promote others to use these findings in the development of interventions wherever possible. For example, I was invited to be part of the Seniors-USP Dissemination Advisory Group. Through this, my findings on ST and employment were included in a handbook for researchers in Scotland who are designing interventions (available in 2018).

Finally, it is important to consider the limitations of Figure 29. The process of evaluation is not explicitly mentioned, as with Figure 8. I argue that it should (but in reality may not) be ubiquitous throughout the interactions, underpinning processes within a group of people or the interactions between them. Some of the arrows may directly reflect evaluation as surveillance is often used to evaluate policy (Choi, 2012). However, to limit evaluation to these arrows may neglect some important evaluation processes that occur within the spheres of academic research, policy, surveillance, and practice. Figure 29 also is not able to reflect some of the barriers to interactions between groups, or whether some processes are more difficult than others; this has been described in this section and reflections in Chapters 6-9. Also, Figure 29 reflects my experiences in Scotland and so may not transfer to other situations involving other risk factors or national governance infrastructures. Indeed, Jung, Nutley, Morton, and Millar (2010) have noted that Scotland's relatively small population, strong policy communities, distinct knowledge exchange funding streams, and consensual policy style differentiate the policy-making process in Edinburgh even from that in London. However, the description of the interactions between academic researchers, practitioners, and those involved in surveillance in the U.S. by Fulton et al. (2016) suggests there will be some parallels with other nations.

12.2.2 Presenting a combined indicator of the physical activity guidelines

This thesis has addressed elements of the U.K. CMOs' PA guidelines individually (Studies 1-3) and in combination (MVPA and ST; Study 5). A recurring discussion within the PhD Steering Group was about the appropriateness of a combined measure of the prevalence of meeting all the recommendations. This has been done with Canadian data for children (Carson, Chaput, Janssen, & Tremblay, 2017). There was policy interest in this: an assumed low prevalence had the potential to help make the case for PA (and ST) against other NCD risk factors. Aside from the issues around a quantified ST recommendation (see Section 8.6), the justification for considering the guidelines in this way hinged on the answers to four questions: (1) were the guidelines intended to be interpreted this way? (2) Does the current evidence support their interpretation in this way? (3) How does one distinguish theoretically and/or statistically between the activities and behaviours? (4) Does this presentation help or hinder efforts to communicate the guidelines to the public?

Regarding (1), the Technical Report for the 2011 U.K. CMOs' PA guidelines suggests that the MSA recommendation was not intended to be equal or concurrent to the MVPA equivalent:

> Overall, the feedback from the web consultation suggest that any statements on the health benefits of strength training…should be positioned as secondary and less important than the primary message to adults of undertaking at least 150 minutes of aerobic activity per week. (Bull & the Expert Working Groups, 2010a, p. 24)

This was based on concerns that the message was too complex and overall demand would be too great, linking to question (4) I posed above. At the time, compliance with the then MVPA recommendation (5x30) was <40% in Scotland (Ormston, 2010), implying that this recommendation was challenging enough.

Regarding (2), there was no published discussion around the epidemiology behind combining the recommendations. Six years on, there is still very mixed evidence. Investigations into the joint effects of MVPA and MSA recommendation compliance on premature mortality are limited by large uncertainty around the estimates (Zhao et al., 2014). Studies using metabolic indicators or multi-morbidity risk as outcomes have shown independent associations for each recommendation (Dankel, Loenneke, & Loprinzi, 2016a, 2016c). However, whether the health effect of MSA and MVPA recommendation compliance is equivalent, or whether their combined effects are greater than additive remains to be seen (Dankel et al., 2016a, 2016c; Stamatakis et al., 2017). The potential interactions between MVPA level and ST have been discussed in Section 11.1. Given the uncertainties and the potentially nuanced interactions, it seems prudent not to create a combined indicator as it may not optimally reflect health risk.

The answer to (3) is more difficult. Although the 2011 U.K. CMOs' PA guidelines state that MSAs should be undertaken 'in addition' to MVPA, the report also notes their overlap (Department of Health, 2011, p. 35). The potential overlap between MVPA, MSAs, and BCAs is also acknowledged (Department of Health, 2011, p. 42). This is compatible with the theoretical concepts described in Chapter 2: some PA can lead to increases in cardio-respiratory fitness, muscle strength and/or balance and co-ordination. However, this poses statistical problems because those meeting one recommendation are often more likely to meet another (e.g. Zhao et al., 2014). Even if one considers MVPA and ST behaviour to be independent, they have been shown to cluster (Ottevaere et al., 2011). If this overlap is considerable then it will be hard for prospective cohort studies to detect their independent long-term health effects, leading to large CIs around the estimates. Future measurement and analysis methods may be able to resolve these tensions, however, it is another justification for not analysing in this way at present.

Finally, in response to (4), the evidence suggests that complex guidelines are more difficult to recall. Knox, Esliger, Biddle, and Sherar (2013) found that 18% of a sample of adults living in England could recall the duration of the current MVPA recommendation, but only 11% could also include an appropriate descriptor of intensity. However, it is not clear that ability to recall the guidelines directly influences behaviour (Abula, Gröpel, Chen, & Beckmann, 2016). M. Kelly and Barker (2016) heavily critique the theoretical basis for knowledge alone changing health behaviour. Nonetheless, communicating health information in a comprehensible format to the general public is a key responsibility of public health officials (Regidor et al., 2007; Silva, Garcia, Rabacow, de Rezende, & de Sa, 2017), and therefore should be considered.

Communicating multiple recommendations was a concern during guideline development (Bull & the Expert Working Groups, 2010a). A well-received infographic has been produced for the adult and older adult guidelines (Reid & Foster, 2016). In combination with social media, this represents a new dissemination pathway for complex health messages (Scott, Fawkner, Oliver, & Murray, 2016). With modern media changing rapidly, these potential avenues should be explored.

In summary, there is currently little justification to support presenting combined prevalence indicator. However, if future research could shed light on the joint effects of the guidelines and/or resolve issues of statistical dependence, this could be an interesting avenue to consider.

12.3 Strengths and Limitations

Specific strengths and weaknesses of each study have been discussed in the relevant chapters so this section will focus on those that concern the thesis as a whole. The main strength of this thesis is that it achieved the stated aim of producing research that has and will continue to inform and enhance PA and SB policy and surveillance in Scotland. This is an indication of three qualities of the work: (1) that it has made a novel contribution to knowledge, (2) that it was undertaken in a scientifically rigorous manner so that the results are trusted, and (3) that it has been communicated in an appropriate way to the target audience(s). These attributes are further confirmed by the fact that the impact of the work goes beyond Scotland, such as U.K.-wide interest in developing new MSA and BCA recommendations and harmonising their surveillance methods.

Another key strength of this thesis is that it used the optimal data source to meet its aims (see Appendix 9). Through using the SHeS, I was able to analyse nationally representative data with sample sizes far larger than had I undertaken primary data collection myself. The work in this thesis comprises the most comprehensive analysis of the PA and ST data collected in the 2012-2015 SHeS to date, and exposed the method to considerable scrutiny. This assisted the interpretation of Studies 1-3 and informed the design of Study 5. As previously described, improvements to the SHeS that result in more valid and reliable estimates not only benefit policy-making but future academic research as well. Utilising this government-funded resource in this way aligns with the Scottish Government's strategy for data access and analysis, ensuring that the maximum public benefit can be gained (The Scottish Government, 2012). I personally have gained research skills through this work, for example, the ability to manage and analyse large datasets and to communicate complex results. I hope to continue to use these to benefit future PA and SB policy and surveillance in Scotland.

However, one could argue that the choice of dataset constrained the analyses. For example, I could not specifically investigate active travel behaviour (a relevant policy topic) because the SHeS does not isolate this domain in its measurement instrument. Also, as the questions for total ST were only introduced in 2012, I was unable to use the earlier datasets that were already linked to health records that would have extended follow-up time for Study 5.

There may also have been preferable alternatives to furthering PA and SB policy and/or surveillance in Scotland. For example, undertaking work to encourage the SHeS to harmonise with global surveillance and use the GPAQ could have been considered. However, my most recent experiences advising on potential updates to the questionnaire have shown me how quickly decisions can be made, and how they may not be based on the factors that academic researchers may prioritise (for example, global harmonisation versus overall survey length). There was therefore a high risk that a thorough investigation of an alternative surveillance method may have been ultimately redundant.

Lastly, in Studies 1-3, I could have considered socio-economic position as a potential correlate alongside age and sex. This would have required combining the data from more years of the survey; something that would have been potentially possible had I modified my timeline of work such that some analyses were delayed until the release of the larger datasets to the U.K. Data Archive. There is good justification for further work to investigate the associations between socio-economic position and PA and ST behaviour amongst adults in Scotland: the latest analysis in the 2016 SHeS Annual Report suggest that the increased levels of compliance seen when the MVPA guideline changed from '5x30' to '150 mins' may not have been uniform with regards to socio-economic position (Currie, 2017). Also, Study 3 showed that there was an interaction effect between age and sex on total ST when stratified by work status, which warrants further investigation. However, whilst this would have added to the work presented in this thesis, it should not have replaced age or sex. These were known strong correlates of total MVPA, and essential demographic factors by which health-related prevalence estimates are presented in Scotland (Bromley, 2013). They were essential covariates to consider in these studies that aimed to influence policy.

12.4 Future Research and Directions for Surveillance in Scotland

During the course of this thesis, I have noted areas for further research where the evidence has been lacking. Some of these topics could have been addressed as part of this thesis had the aims and scope been different (e.g. points 1 and 5 in the list below). Others needed alternative methods, greater time and/or resources, but potentially could have been addressed through a PhD programme of work that was focused on the topic (e.g. 2 and 10). Some are likely to be issues that the whole field of PA and SB epidemiology will grapple with for many years to come, requiring innovative research methods, replication, and evaluation (e.g. 3, 4, 6-10). These areas are:

1. the domain-specific health benefits of occupational and domestic MVPA (see Section 6.5.3);
2. how MVPA levels change with retirement and what factors influence this (see Section 6.5.4);
3. the types of MSAs and BCAs that promote health benefits, and the volume, repetitions, and intensity required (see Section 7.7);
4. devising appropriate methods to measure population-level compliance with the MSA and BCA recommendations (see Sections 7.7 and 9.6.2);
5. the reasons for high ST amongst men not in employment (see Section 8.5.2);
6. the dose-response relationships between ST and health outcomes (see Section 8.6);
7. the possible causal relationships between MVPA, ST, and health outcomes (see Section 11.1);
8. population-level interventions that may change PA and ST behaviours (see Section 12.2.1);
9. the issues around presenting a combined indicator of the PA guidelines (see Section 12.2.2); and

10. undertaking a direct assessment of the validity and reliability properties of the SHeS (see Section 12.3).

Considering the long-term issues for our field is particularly important when advising on surveillance because trend data are valuable to policy-makers and because national surveys can be unparalleled research resources (Brennan, Perola, van Ommen, & Riboli, 2017). Considering now what measures one would like in the next decade's prospective cohort studies is advantageous for researchers too. For example, NHANES first used accelerometers in 2003 and these data have been hugely influential in the field of PA and SB epidemiology despite using a different version of the device in later surveys (Troiano et al., 2014). It may also be important to be prepared to measure ST with an objective monitor if a quantified ST recommendation is to be derived from such data. This is not as unrealistic for the SHeS as it was previously. Unit costs are decreasing, data analysis software is improving, and compliance issues are gradually being resolved. For example, the Seniors-USP project has developed a protocol that minimises data loss (unpublished data). The person-power required to administer and collect the units (and associated costs) may still be unrealistic for annual national data collection. However, innovative solutions such as rotating the units between the four U.K. home nations' surveys, or only using a sub-sample, could reduce this burden and the initial unit costs. The benefits of such an initiative are more than financial. Pooling national datasets would create an invaluable resource in the efforts to tackle the burden of chronic disease (Brennan et al., 2017).

Introducing devices in the near future may also generate useful data for developing an MVPA recommendation derived from objective measures. If run concurrently with the MVPA questionnaire, the data could provide greater insight on how to compare the results derived from the different methods. However, until a device is able to infer the domain of the activity (potentially through incorporation of global positioning system receivers; del Rosario, Redmond, & Lovell, 2015) there is likely to be a role for self-reported measurement instruments.

It would be remiss not to consider the potential role that wearable tracker, smartphone data and/or the data collected through shared platforms may play in the future. The recent study by Althoff et al. (2017) demonstrated the potential of such data. With response rates to surveys declining worldwide (C. L. Craig et al., 2016), it is worth considering what the barriers are to replacing national surveillance with such methods. The focus so far has been on whether the measurement and analysis methods produce valid and reliable results (Evenson, Wen, Metzger, & Herring, 2015). My work on Study 4 showed that the external validity of the results needs to be considered as well. This leads me to question whether the study design is actually the bigger issue for data derived from such sources. The 2012-15 SHeS can produce nationally representative estimates as the probability sampling methods allowed weights to be derived that accounted for non-response bias. If this issue could be resolved for these data sources, then PA and SB surveillance could change dramatically from what we know it to be now.

12.5 Conclusions

This thesis comprises of novel secondary analyses of the 2012-15 SHeS data. This answered the identified knowledge gaps relating to the MVPA, MSA, BCA, and ST behaviours of adults in Scotland. It achieved its aim of informing Scottish PA and SB policy and surveillance and has the potential to continue to do so. I have concluded that the areas of academic research, policy, and surveillance can mutually benefit from greater interaction, although this may require additional effort on the part of the individuals involved.

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Appendices

1. List of presentations and posters

Presentations (presenter underlined)

Strain, T. (2016). What types of physical activity do adults in Scotland do? Presentation to Health and Social Care team at St Andrews House, The Scottish Government, Edinburgh, 2nd June.

Kelly, P., & Strain, T. (2016). Domain comparisons of physical activity in adults by age and gender in Scotland. Presentation at HEPA Europe, Belfast, 29th September.

Strain, T. (2016). Comparisons of domain-specific physical activity between home nations. Presentation at HEPA Europe, Belfast, 29th September.

Strain, T., Baker, G., Fitzsimons, C., & Kelly, P. (2016). Pilot testing the 'Edinburgh Framework': Use of a novel approach to establish the validity and reliability of the Scottish Health Survey. Presentation at HEPA Europe, Belfast, 29th September.

Strain, T. (2016). Differences by age and gender in the total reported weekday sitting time for adults in Scotland. Presentation at the Scottish Physical Activity Research Conference, 24th October.

Strain, T. (2017). Considering work status when analysing data on the total sitting time of adults in Scotland. Invited presentation at Glasgow Caledonian University, 17th March.

Strain, T. (2017). Using the Scottish Health Survey sedentary behaviour data to influence policy and practice. Presentation at an internal conference at the Institute of Sport, Physical Education, & Health Sciences, University of Edinburgh, 26th April.

Posters

Mutrie, N., Strain, T., Fitzsimons, C., & Kelly, P. (2015). Domain-specific physical activity data from the Scottish Health Survey to inform policy and practice. Presented as a poster at BASES Conference, 2nd December.

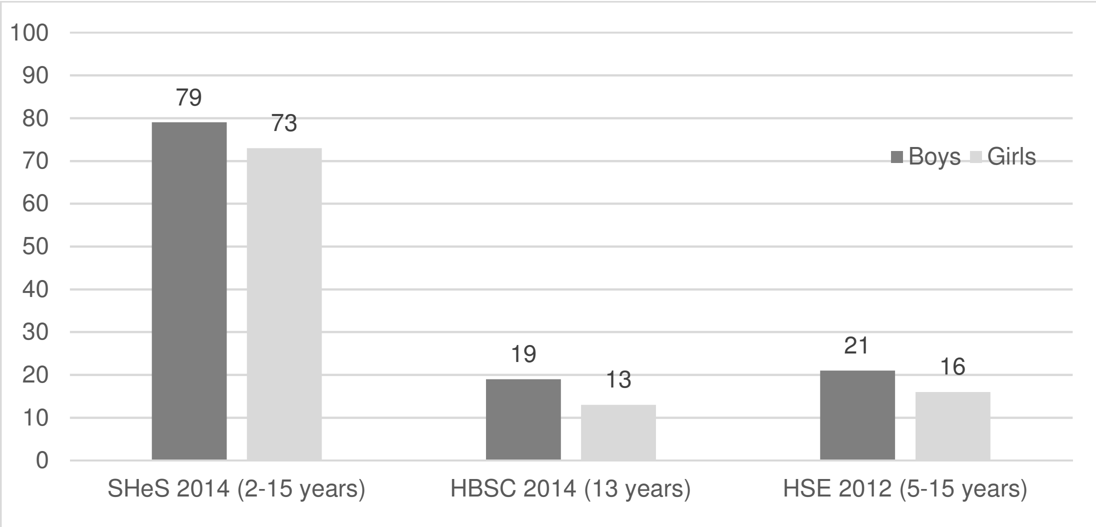
Strain, T., Mutrie, N., Fitzsimons, C., & Kelly, P. (2016). Domain-specific physical activity data from the Scottish Health Survey to inform policy and practice. Presented as a poster at an internal conference at the Institute of Sport, Physical Education, & Health Sciences, University of Edinburgh, 13th December.

2. Measurement of child physical activity in Scotland and England

Summary sent to the Scottish Government in October 2017. Based on work by Chloe Williamson for her MSc. Physical Activity for Health dissertation. I was co-supervisor with Dr Paul Kelly at the Physical Activity for Health Research Centre, University of Edinburgh.

There are large differences in prevalence figures for child physical activity (PA) between the Scottish Health Survey (SHeS) and the Health Survey for England (HSE). There are also differences between the SHeS and other surveys within Scotland such as the Health Behaviour in School-aged Children (HBSC; Figure 1).

Figure 1. The proportion of children meeting the physical activity guideline as estimated by different national surveys



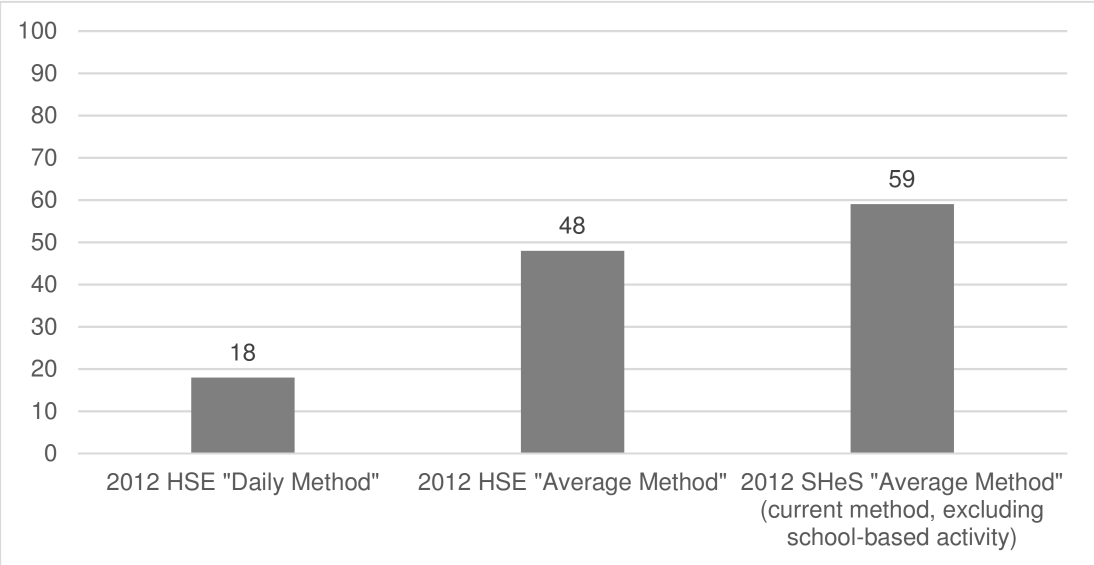
This is problematic for two reasons: (1) it questions the validity of the national statistics, and (2) it limits between country comparisons. The disagreements over the use of data in the 2016 Active Healthy Kids Report Card are an example of both these points.

Some have suggested that the high prevalence figures derived from the SHeS are due to poor measurement of intensity, meaning light intensity activities are included when they should not be. We queried this as the HSE follows a similar measurement method yet produces low prevalence estimates.

Instead, we suggested that different interpretations of the guidelines resulting in different analysis methods may explain some of the difference. The HSE considers a child to meet the guidelines if they are active for 60 minutes of each of the 7 days prior to interview (the ‘daily method’ (DM)). The SHeS considers a child to be active if they have undertaken at least 7 sessions of activity, and the average daily duration is at least 60 minutes (the ‘average method’ (AM)).

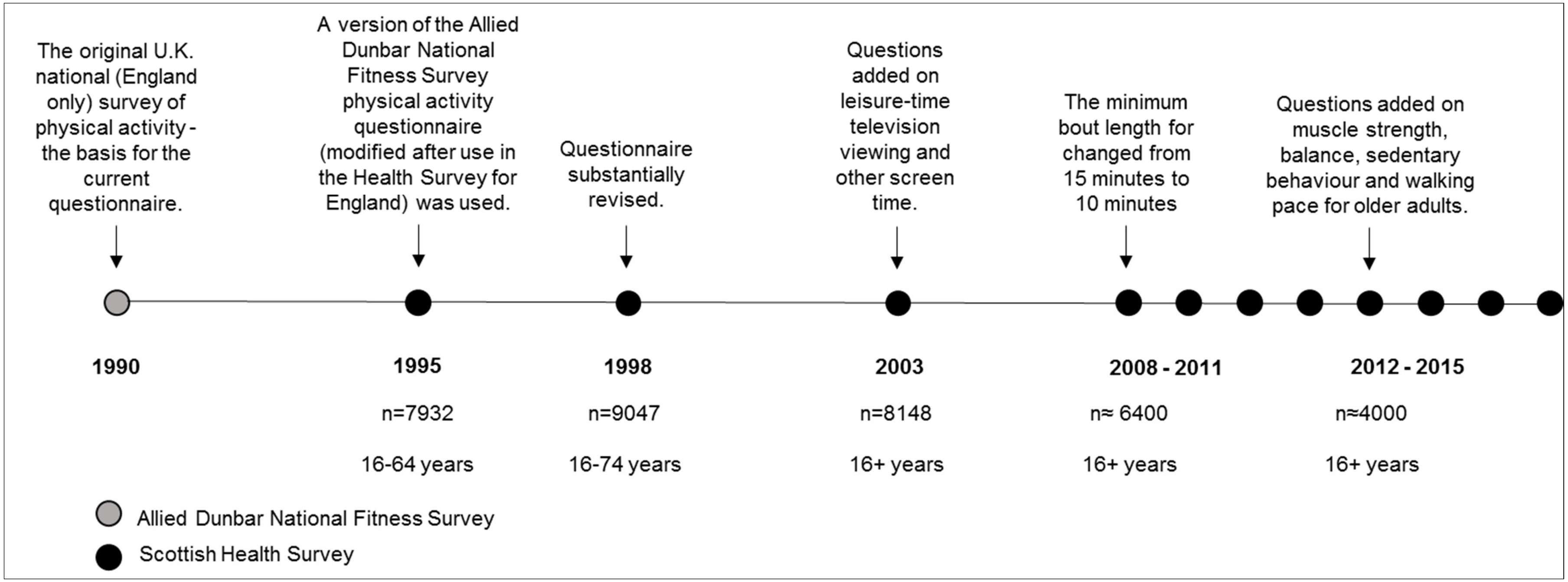
We reanalysed the 2012 HSE data according to the AM and derived comparable figures from the 2012 SHeS (i.e. excluding school-based activity). As Figure 2 shows, this accounted for a large proportion of the difference between the surveys.

Figure 2. The proportion of children meeting the physical activity guideline as estimated by different surveys and analysis methods



This information will assist those deciding whether to modify the SHeS questionnaire as it is currently unable to use the DM for analysis. It implies that considerably lower prevalence figures would be expected if the SHeS was changed so that it could be analysed according to the DM. This may encourage greater ‘trust’ in the figures, and potentially allow for between country comparisons. However, it would break trend data and would alter the backdrop to child PA policy in Scotland.

3. Scottish Health Survey questionnaire developments



4. U.K. Data Archive End User Licence

The full licence can be found at:
https://www.ukdataservice.ac.uk/media/455131/cd137-enduserlicence.pdf

The following summary is found on the UK Data Archive website:
https://www.ukdataservice.ac.uk/get-data/how-to-access/conditions

The summary below is for general guidance and you must read and understand the full EUL before agreeing to it. By accepting it you agree:

- to use the data in accordance with the EUL and to notify the U.K. Data Service of any non-compliance you are aware of
- not to use the data for commercial purposes without obtaining permission and, where relevant, an appropriate licence if commercial use of the data is required
- that the EUL does not transfer any interest in intellectual property to you
- that the EUL and data collections are provided without warranty or liability of any kind
- to abide by any further conditions notified to you
- to give access to the data collections only to registered users with a registered use (who have accepted the terms and conditions, including any relevant further conditions). There are some exceptions regarding the use of data collections for teaching and the use of data collections for Commercial purposes set out in an additional Commercial Licence
- to ensure that the means of access to the data (such as passwords) are kept secure and not disclosed to anyone else
- to preserve the confidentiality of, and not attempt to identify, individuals, households or organisations in the data
- to use the correct methods of citation and acknowledgement in publications
- to send the U.K. Data Service bibliographic details of any published work based on our data collections
- that personal data about you may be held for validation and statistical purposes and to manage the service, and that these data may be passed on to other parties
- to notify the U.K. Data Service of any errors discovered in the data collections
- that personal data submitted by you are accurate to the best of your knowledge and kept up to date by you
- to meet any charges that may apply
- to offer for deposit any new data collections which have been derived from the materials supplied
- will destroy ***all*** copies of the data to the standards specified in point 1.16
- will ensure that the data are destroyed to the standards specified in the Microdata Handling and Security: Guide to Good Practice
- that any non-compliance of the EUL will lead to immediate termination of your access to the services and could result in legal action against you

5. Linking the Scottish Health Survey to Health Records

The following questions are asked of all respondents aged 16 years and over[3]:

[NHSCanA]
We would like your consent for us to send your name, address and date of birth to the Information Services Division of NHS Scotland so they can link it with your NHS health records. These records hold data on you about medical diagnoses and in-patient and out-patient visits to hospital. They are linked with other information about cancer registration, GP registration and mortality. Please read this form, it explains more about what is involved.
INTERVIEWER: Give the respondent/s the **pale green** consent form (Scottish health records) and allow them time to read the information.
This form is included as part of this appendix.

[NHSCon]
INTERVIEWER: Did respondent give consent?
1 Consent given
2 Consent not given

If consent is given, a SHeS respondent's interview data are linked to health records through a three-step process. This avoids any one organisation having access to all three elements (personal details, survey data, and health records) at any one time. This would be a breach of the Data Protection Act[4].

Figure 1 shows the first step: the data providers (ScotCen) provide the holders of the health records (ISD) with a dataset containing the respondents' personal details and a dummy ID. Figure 2 shows the second step: ISD use these personal details to match the dummy ID to the health records in a new dataset. Figure 3 shows the third step: both ScotCen and ISD pass anonymised datasets to a third party (the Scottish Government). ScotCen pass on the survey data and ISD pass on the health records. They can be matched based on the dummy ID which is non-identifiable.

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[3] For full questionnaire see Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government
[4] Data Protection Act (1998). London, U.K., Stationary Office. http://www.legislation.gov.uk/ukpga/1998/29/pdfs/ukpga_19980029_en.pdf

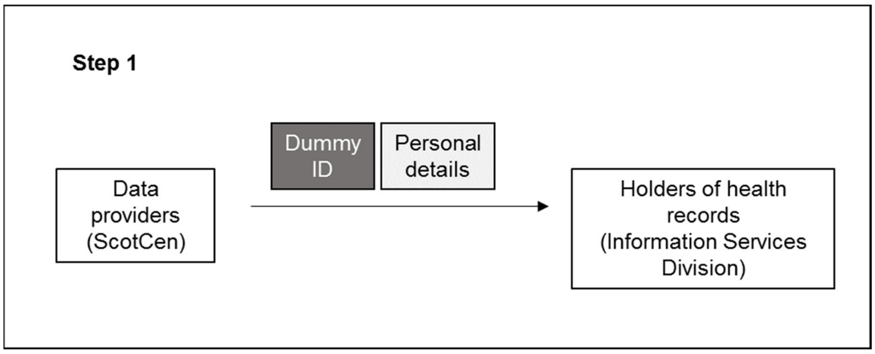

Figure 1. Step 1 of linking Scottish Health Survey interview data to health records.

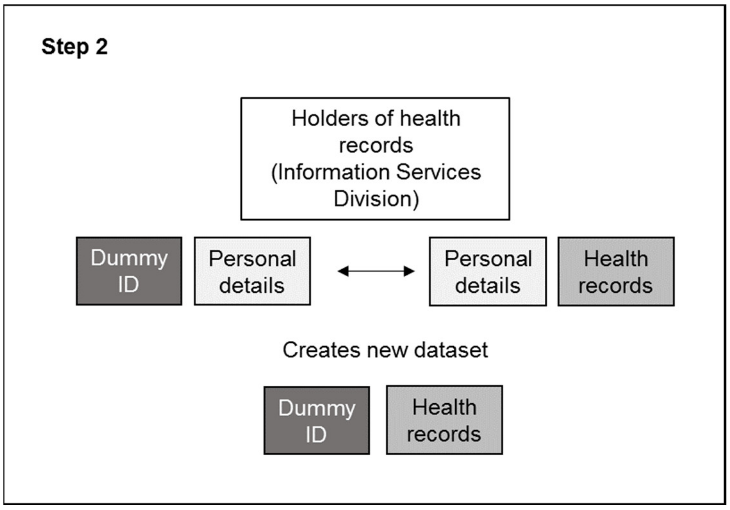

Figure 2. Step 2 of linking Scottish Health Survey interview data to health records.

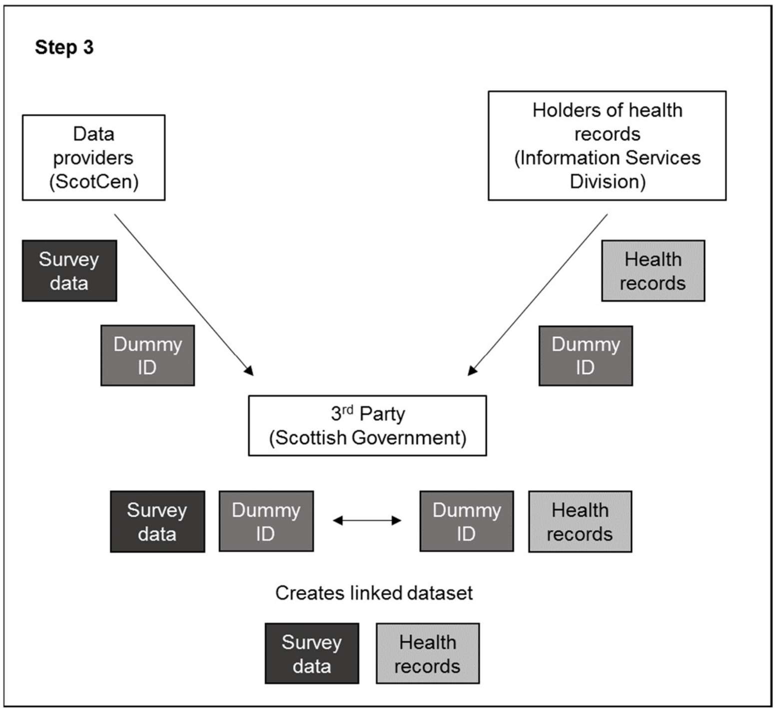

Figure 3. Step 3 of linking Scottish Health Survey interview data to health records.

ScotCen Social Research

NHS SCOTLAND

The Scottish Government
Riaghaltas na h-Alba

Ref number.

NHS (A)

SCOTTISH HEALTH SURVEY

Scottish Health Records

(Adults 16+)

- The National Health Service (NHS) maintains routine medical and other health records on all patients who use their services. These records include:
  - In-patient and out-patient visits to hospital, length of stay and waiting times.
  - Information about specific medical conditions such as cancer, heart disease and diabetes.
  - Details about registration with a general practitioner, and when people pass away, the date and cause of their death.
- We would like to ask for your consent to link your NHS health records with your survey answers.
- To link this information we need to send your name, address and date of birth to the Information Services Division (ISD) of NHS Scotland so they can identify your health records.
- By linking this information with the interview data the research is more useful as we can look at how people's lifestyle and circumstances can have an impact on their future health and use of hospital services.
- This information will be confidential and used for statistical and research purposes only. The information will not identify you so it cannot be used by anyone treating you as a patient.
- By signing this form you are only giving permission for the linking of this information to routine administrative data and nothing else.
- You can cancel this permission at any time in the future by writing to: ScotCen Social Research, Scotiabank House, 2nd Floor, 6 South Charlotte Street, Edinburgh, EH2 4AW. You do not need to give a reason to cancel this.

Your consent

I, (name) ______________________________ consent to ScotCen Social Research passing my name, address and date of birth to:

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Signed ______________________________ *Date* ____________________

I understand that these details will be used for statistical and research purposes only.

P97192.01 U CON HR (A)

6. The 2012-15 Scottish Health Survey questionnaire

Questionnaire from Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government.

ASK ALL AGED 16+
[Work]
I'd like to ask you about some of the things you have done in the past four weeks that involve physical activity, this could be at work *(school)* college or in your free time. (Can I just check) were you in paid employment or self-employed in the past four weeks?
1 Yes
2 No

IF Work = Yes THEN [Active]
Thinking about your job in general would you say that you are ...READ OUT..
1 ...very physically active,
2 ...fairly physically active,
3 ...not very physically active,
4 ...or, not at all physically active in your job?

[MainSit]
When you are at work are you mainly sitting down, standing up or walking about?
1 Sitting down
2 Standing up",
3 Walking about",
4 Equal time spent doing 2 or more of these

On an average work day in the last four weeks, how much time did you usually spend sitting down?
INTERVIEWER: IF RESPONDENT WAS ON HOLIDAY OR UNABLE TO WORK ON ANY DAYS IN THE LAST FOUR WEEKS, ASK THEM TO REPORT THE AVERAGE NUMBER OF HOURS ON THOSE DAYS THEY WORKED.

[WrkAct3H]
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR. RECORD MINUTES AT NEXT QUESTION

[WrkAct3M]
ENTER NUMBER OF MINUTES. IF AN EXACT HOUR, ENTER 0 FOR MINUTES (0..59)

ASK ALL AGED 16+
[Housewrk]
I'd like you to think about the physical activities you have done in the last few weeks *(when you were **not** doing your paid job.)* Have you done any housework in the past four weeks, that is from *(date four weeks ago)* up to yesterday?
1 Yes
2 No

IF Housewrk = Yes THEN [HWrkList]
SHOW CARD E1: Hoovering, dusting, ironing, general tidying, washing floors and paint work.
Have you done any housework listed on this card?
1 Yes
2 No

[HevyHWrk]
SHOW CARD E2: Moving heavy furniture, spring cleaning, walking with heavy shopping (more than 5 minutes), cleaning windows, scrubbing floors with a scrubbing brush.
Some kinds of housework are heavier than others. This card gives some examples of heavy housework. It does not include everything, these are just examples.
Was any of the housework you did in the last four weeks this kind of heavy housework?
1 Yes
2 No

IF HevyHWrk = Yes THEN [HeavyDay]
During the past four weeks on how many **days** have you done this kind of **heavy** housework?
Range: 1..28

[HrsHHW]
On the days you did heavy housework, how long did you usually spend?
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR. RECORD MINUTES AT NEXT QUESTION; Range: 0..12

[MinHHW]
RECORD MINUTES SPENT ON HEAVY HOUSEWORK.
Range: 0..59

ASK ALL AGED 16+
[Garden]
Have you done any gardening, DIY or building work in the past four weeks, that is since *(date four weeks ago)*?
1 Yes
2 No

IF Garden = Yes THEN [GardList]
SHOW CARD E3: hoeing, weeding, pruning, mowing with a power mower, planting flowers/seeds, decorating, minor household repairs, car washing and polishing, car repairs and maintenance.
Have you done any gardening, DIY or building work listed on this card?
1 Yes
2 No

[ManWork]
SHOW CARD E4: Digging, clearing rough ground, building in stone/bricklaying, mowing large areas with a hand mower, felling trees, chopping wood, mixing/laying concrete, moving heavy loads, refitting a kitchen or bathroom.

Have you done any gardening, DIY or building work from this other card, or any similar heavy manual work?
1 Yes
2 No

IF ManWork = Yes THEN [ManDays]
During the past 4 weeks on how many **days** have you done this kind of **heavy** manual gardening or DIY?
Range: 1..28

[HrsDIY]
On the days you did heavy manual gardening or DIY, how long did you usually spend?
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR. RECORD MINUTES AT NEXT QUESTION.
Range: 0..12

[MinDIY]
RECORD MINUTES SPENT ON GARDENING OR DIY.
Range: 0..59

ASK ALL AGED 16+
[Wlk5Int]
I'd like you to think about **all** the **walking** you have done in the past 4 weeks either locally or away from here. Please include any country walks, walking to and from work and any other walks that you have done. In the past four weeks, that is since *(date four weeks ago)*, have you done a **continuous** walk that lasted **at least** 5 minutes?
1 Yes
2 No
3 Can't walk at all

IF Wlk5Int = Yes THEN [Wlk10M]
In the past four weeks, have you done a **continuous** walk that lasted **at least** 10 minutes? (That is since *(date four weeks ago))*
1 Yes
2 No

IF Wlk10M = Yes THEN [DayWlk10]
During the past four weeks, on how **many days** did you do a **continuous** walk of at least 10 minutes? (That is since *(date four weeks ago))*
IF THEY WALKED EVERYDAY ENTER 28
Range: 1..28

[Day1Wk10]
On that day (any of those days) did you do **more than one continuous** walk lasting at least 10 minutes?
1 Yes, more than one walk of 10+ mins (on at least one day)
2 No, only one walk of 10+ mins a day

IF (DayWlk10 in 2..28) AND (Day1Wk10 = Yes) THEN [Day2Wk10]
On how many days in the last four weeks did you do **more than one** walk that lasted at least 10 minutes?
Range: 1..28

IF Wlk10M = Yes THEN [HrsWlk10]
How long did you usually spend walking each time you did a **continuous** walk for 10 minutes or more?
INTERVIEWER: IF VERY DIFFERENT LENGTHS, PROBE FOR MOST REGULAR.
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR.
RECORD MINUTES AT NEXT QUESTION.
Range: 0..12

[MinWlk10]
INTERVIEWER: RECORD HERE MINUTES SPENT WALKING.
Range: 0..59

IF Wlk5Int = Yes THEN [WalkPace]
Which of the following best describes your **usual** walking pace ...READ OUT...
1 ...a slow pace,
2 ...a steady average pace,
3 ...a fairly brisk pace,
4 ...or, a fast pace - at least 4 mph?
5 (none of these)

IF (Wlk15M = Yes) AND (Age>= 65) THEN [WalkEff]
During the past four weeks, was the effort of walking for 10 minutes or more usually enough to make you breathe faster, feel warmer, or sweat?
1 Yes
2 No

ASK ALL AGED 16+
[ActPhy]
SHOW CARD E5
Can you tell me if you have done any activities on this card during the last 4 weeks, that is since (date four weeks ago)? Include teaching, coaching, training and practice sessions.
1 Yes
2 No

IF ActPhy = Yes THEN [WhtAct]
Which have you done in the last four weeks? CODE ALL THAT APPLY.

1 Swimming	[WhtAct01]
2 Cycling	[WhtAct02]
3 Workout at a gym/Exercise bike/ Weight training	[WhtAct03]
4 Aerobics/Keep fit/Gymnastics/ Dance for fitness	[WhtAct04]
5 Any other type of dancing	[WhtAct05]
6 Running/ Jogging	[WhtAct06]
7 Football/ Rugby	[WhtAct07]
8 Badminton/ Tennis	[WhtAct08]
9 Squash	[WhtAct09]
10 Exercises (e.g. press-ups, sit ups)	[WhtAct10]

[WhtAcB]1
And have you done any of the activities on this card in the last four weeks? Please just tell me the numbers

0 - No - none of these	[WhtAcB0]
1 – Bowls	[WhtAcB01]
2 - Fishing/angling	[WhtAcB02]
3 – Golf	[WhtAcB03]
4 - Hillwalking/rambling	[WhtAcB04]
5 - Snooker/billiards/pool	[WhtAcB05]
6 - Aqua-robics/aquafit/exercise class in water	[WhtAcB06]
7 - Yoga/pilates	[WhtAcB07]
8 – Athletics	[WhtAcB08]
9 – Basketball	[WhtAcB09]
10 - Canoeing/Kayaking	[WhtAcB10]
11 – Climbing	[WhtAcB11]
12 – Cricket	[WhtAcB12]
13 – Curling	[WhtAcB13]
14 – Hockey	[WhtAcB14]
15 - Horse riding	[WhtAcB15]
16 - Ice skating	[WhtAcB16]
17 - Martial arts including Tai Chi	[WhtAcB17]
18 – Netball	[WhtAcB18]
19 - Powerboating/jet skiing	[WhtAcB19]
20 – Rowing	[WhtAcB20]
21 - Sailing/windsurfing	[WhtAcB21]
22 – Shinty	[WhtAcB22]
23 - Skateboarding/inline skating	[WhtAcB23]
24 - Skiing/snowboarding	[WhtAcB24]
25 – Subaqua	[WhtAcB25]
26 - Surfing/body boarding	[WhtAcB26]
27 - Table tennis	[WhtAcB27]
28 - Tenpin bowling	[WhtAcB28]
29 – Volleyball	[WhtAcB29]
30 – Waterskiing	[WhtAcB30]

ASK ALL AGED 16+
REPEAT FOR UP TO 6 ADDITIONAL SPORTS, WHEN ANSWER YES AT EACH SUCCESSIVE 'OTHER ACTIVITY' VARIABLE OActQ11 to OActQ16
[OactQ]* *(Variable names: OActQ11-OActQ16)*
Have you done any other sport or exercise not listed on the card?
1 Yes
2 No

IF OActQ = Yes THEN WHTACT11 – WHT16
For each activity, a set of questions about number of days/hours/minute and effort was asked:
[swimocc to wskiocc]
Can you tell me on how many separate days did you do *(name of activity)* for at least 10 minutes a time during the past four weeks, that is since *(date four weeks ago)?*
IF ONLY DONE FOR LESS THAN 10 MINUTES ENTER 0.
Range: 0..28

[swimhrs to wskihrs]
How much time did you usually spend doing *(name of activity)* on each day? (Only count times you did it for at least 10 minutes).
RECORD HOURS SPENT BELOW.
ENTER 0 IF LESS THAN 1 HOUR.
RECORD MINUTES AT NEXT QUESTION.
Range: 0..12

[swimmin to wskimin]
INTERVIEWER: RECORD MINUTES HERE.
Range: 0..59

[swimeff to wskieff]
During the past four weeks, was the effort of (name of activity) usually enough to make you out of breath or sweaty?
1 Yes
2 No

For certain activities an additional question was asked to identify whether the activity could be classed as muscle strengthening.
IF WhtAct, WhtAcB or OactQ = cycling, workout at a gym, aerobics, any other type of dancing, running/jogging, football/rugby, badminton/tennis, squash, exercises, ten pin bowling, yoga/pilates, aquarobics/aquafit, martial arts/Tai Chi, basketball, netball, lawn bowls, golf, hill walking/rambling, cricket, hockey, curling, ice skating, shinty, surf/body boarding, volleyball **THEN [cyclemus to Vollmus]**

During the past four weeks, was the effort of (name of activity) usually enough to make your muscles feel some tension, shake or feel warm?
1 Yes
2 No

IF WhtAct = Exercises (e.g. press-ups, sit-ups) AND (Age>=65) THEN
[ExMov][2]
Did these exercises involve you standing up and moving about?
1 Yes
2 No

ASK ALL AGE 16+
[TVWeek]
Thinking first of weekdays, that is Monday to Friday, how much time on **an average day** do you spend watching TV or another type of screen such as a computer, game boy, or video game? Please do **not** include any time spent in front of a screen while at nursery or school.
RECORD **HOURS** SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR OR NEVER WATCHES SCREEN. RECORD MINUTES AT NEXT QUESTION.
Range: 0..12

[MinTVWk]
RECORD MINUTES HERE.
Range: 0..59

And how much time on an average weekday do you spend sitting down doing any other activity, such as eating a meal, reading, or listening to music or [if over 65] napping in a chair Please do not include time spent doing these activities while at work**.**
INTERVIEWER: OTHER EXAMPLES OF THESE ACTIVITIES INCLUDE SNACKING, STUDYING, DRAWING, DOING PUZZLES/CROSSWORDS ETC. DO NOT COUNT TIME TWICE E.G. IF THEY WATCH TV AND EAT, INCLUDE THAT HERE OR AT PREVIOUS QUESTION - NOT BOTH.

[WkSit2H]
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR. RECORD MINUTES AT NEXT QUESTION: 0..24

[WkSit2M]
RECORD MINUTES HERE:0..59

[TVWkEnd]
Now thinking of the weekend, that is Saturday and Sunday, how much time on **an average day** do you spend watching TV or another type of screen (such as a computer, game boy, or video game)? Again, please do **not** include any time spent in front of a screen while at nursery or school.
RECORD **HOURS** SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR OR NEVER WATCHES SCREEN. RECORD MINUTES AT NEXT QUESTION.
Range: 0..12

[MinTvWe]
RECORD MINUTES HERE.
Range: :0..59

And how much time on an average weekend day (that is Saturday and Sunday) do you spend sitting down doing any other activity, such as eating a meal, reading, or listening to music or [if over 65] napping in a chair. Please do not include time spent doing these activities while at work.
INTERVIEWER: OTHER EXAMPLES OF THESE ACTIVITIES INCLUDE SNACKING, STUDYING, DRAWING, DOING PUZZLES/CROSSWORDS ETC. DO NOT COUNT TIME TWICE E.G. IF THEY WATCH TV AND EAT, INCLUDE THAT HERE OR AT PREVIOUS QUESTION - NOT BOTH.

[WESit2H]
RECORD HOURS SPENT BELOW. ENTER 0 IF LESS THAN 1 HOUR. RECORD MINUTES AT NEXT QUESTION.
0..24

[WESit2M]
RECORD MINUTES HERE. 0..59

7. Aerobic intensity levels of sport and exercise activities assigned by the 2012-15 Scottish Health Survey

Sport	Intensity level	Sport	Intensity level
Darts	Light	Sailing/Windsurfing	Moderate or vigorous
Shooting	Light	Dancing (any other)	Moderate or vigorous
Snooker/billiards/ pool	Light	Exercises	Moderate or vigorous
Tenpin bowling	Light	Basketball	Moderate or vigorous
Canal cruising	Light	Canoeing/Kayaking	Moderate or vigorous
Post-natal exercise	Light	Ice skating	Moderate or vigorous
Toning table/bed	Light	Netball	Moderate or vigorous
Other light	Light	Rowing	Moderate or vigorous
Fishing/angling	Light or moderate	Skateboarding/Inline skating	Moderate or vigorous
Yoga/pilates	Light or moderate	Skiing/snowboarding	Moderate or vigorous
Walking/jogging on treadmill	Light or moderate	Volleyball	Moderate or vigorous
Bowls	Moderate	Field athletics	Moderate or vigorous
Golf	Moderate	Swimming	Moderate or vigorous
Cricket	Moderate	Cycling	Moderate or vigorous
Table tennis	Moderate	Workout at gym/Ex bike/Weights	Moderate or vigorous
Abseiling/ parasailing	Moderate	Aerobics/keep fit/gym/dance for fitness	Moderate or vigorous
Baseball/softball	Moderate	Badminton/Tennis	Moderate or vigorous
Croquet	Moderate	Running/jogging	Moderate or vigorous
Rounders	Moderate	Boxing	Moderate or vigorous
Snorkelling	Moderate	Hill walking/Rambling	Moderate or vigorous
Fencing	Moderate	Aquarobics	Moderate or vigorous
Trampolining	Moderate	Athletics	Moderate or vigorous

Curling	Moderate	Climbing	Moderate or vigorous
Surf/body boarding	Moderate	Martial Arts incl. Tai Chi	Moderate or vigorous
Water Skiing	Moderate	Powerboating/Jet Skiing	Moderate or vigorous
Adventure playground	Moderate	American Football	Moderate or vigorous
Archery	Moderate	Circuit Training	Moderate or vigorous
Assault Course	Moderate	Hiking	Moderate or vigorous
Battle re-enactment	Moderate	Riding	Moderate or vigorous
Diving	Moderate	Territorial Army	Moderate or vigorous
Dog training	Moderate	Hockey	Vigorous
Drumming (in a group)	Moderate	Lacrosse	Vigorous
Hang gliding	Moderate	Football/rugby	Vigorous
Hitting punch sack	Moderate	Squash	Vigorous
Juggling	Moderate	Kick boxing	Vigorous
Kabadi	Moderate	Skipping	Vigorous
Motor sports	Moderate	Shinty	Vigorous
Skirmishing (war games)	Moderate	Subaqua	Vigorous
Skittles	Moderate	Backpacking	Vigorous
Sumo wrestling	Moderate	Fives	Vigorous
Swing ball	Moderate	Marathon running	Vigorous
Weight lifting	Moderate	Orienteering	Vigorous
Wrestling	Moderate	Polo	Vigorous
Other moderate	Moderate	Racket ball	Vigorous
Horse Riding	Moderate or vigorous	Other vigorous	Vigorous

Note. When there is an alternative, the answer to ‘does the activity make you breathe faster, feel warmer, or sweat?’ is used to determine intensity level. For more information see Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government.

8. Muscle strength and balance and co-ordination activities in the 2012-15 Scottish Health Surveys

This information is from Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government.
It was also included as 'Additional File 1' to Strain, T., Fitzsimons, C. F., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. BMC Public Health, 16(1) 1108. doi: 10.1186/s12889-016-3774-6

Categories of muscle strengthening sport and exercise activities in the Scottish Health Survey

1. Activities that are always counted as muscle strengthening:
   Swimming, athletics, sailing/wind surfing, skiing/snowboarding, horse riding, waterskiing, rowing, canoeing/kayaking, climbing
2. Activities that require a follow-up question to count as muscle strengthening:
   Cycling, weight training/workout at a gym/exercise bike, aerobics/keep fit/gymnastics/dance for fitness, any other type of dancing, running/jogging, football/rugby, badminton/tennis, squash, exercises, ten pin bowling, yoga/pilates, aquarobics/aquafit, martial arts/Tai Chi, basketball, netball, lawn bowls, golf, hill walking/rambling, cricket, hockey, curling, ice skating, shinty, surf/body boarding, volleyball

The follow-up question for muscle strengthening activities is:

> During the past four weeks, was the effort of (name of activity) usually enough to make your muscles feel some tension, shake or feel warm? Yes/No

Categories of balance & co-ordination sport and exercise activities in the Scottish Health Survey

1. Activities that are always count as balance and co-ordination improving:
   Cycling, weight training/workout at a gym/exercise bike, aerobics/keep fit/gymnastics/dance for fitness, any other type of dancing, football/rugby, badminton/tennis, squash, horse riding, aquafit/aquarobics, jet ski, climbing, lawn bowls, golf, hill walking/rambling, yoga/pilates, athletics, basketball, netball, canoeing/kayaking, cricket, hockey, curling, ice skating, martial arts/tai chi, sailing/wind surfing, shinty, surf/body boarding, skiing/snowboarding, ten pin bowling, table tennis, volleyball, waterskiing
2. Activities that require a follow-up question to count as balance and co-ordination improving:
   Exercises

The follow-up question for balance and co-ordination activity (exercises) is:

> Did these exercises involve you standing up and moving about? Yes/No

9. Nationally representative physical activity and sedentary behaviour data in Scotland

Survey	Types of physical activity and sedentary time included in 2011 U.K. CMOs' PA guidelines				Domains of moderate-to-vigorous physical activity	Demographic variables e.g. age and sex	Longitudinal follow-up of health outcomes	Sample size
	'150 mins'	Muscle strengthening activity	Balance and co-ordination activity	Sedentary time				
2012-2015 Scottish Health Survey[a]	✓	✓	✓	✓	✓	✓	✓ (with 1.5 year time-lag)	4000-5000 per year
2008-2011 Scottish Health Survey[b]	✓	X	X	TV viewing only	✓	✓	✓	6000 per year
2003 Scottish Health Survey[c]	✓	No	No	TV viewing only	✓	✓	✓	9000
Scottish Household Survey[d]	X	X	X	X	Sport and exercise, walking, and active travel	✓	X	11,000 households
National Travel Survey[e]	X	X	X	X	Travel only	✓	X	750-1500 households

Note. [a]Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government; [b]Corbett, J., et al. (2009). The Scottish Health Survey 2008. Volume 2: Technical Report. Edinburgh: The Scottish Government; [c]Bromley, C., et al. (2004). The Scottish Health Survey 2003. Volume 4: Technical Report. Edinburgh: The Scottish Government; [d]The Scottish Household Survey Project Team. (2015). Scotland's People Annual Report: Results from the 2014 Scottish Household Survey. Edinburgh: The Scottish Government; [e]Ceased sampling in Scotland in 2012, The Scottish Government. (2010). National Travel Survey Scottish Results 2007-2008. Edinburgh: The Scottish Government.

10. Supplementary materials for Study 1

The following information was included as Supplementary Materials in the publication: Strain, T., Fitzsimons, C.F., Foster, C., Mutrie, N., Townsend, N., & Kelly, P. (2016). Age-related comparisons by sex in the domains of aerobic physical activity for adults in Scotland. Preventive Medicine Reports, 3, 90-97.

Exercise & fitness
Workout at gym/Exercise bike/Weight training*, Swimming^, Running/jogging*, Walking/jogging on treadmill˅, Exercise (e.g. press ups, sit ups)*, Aerobics/Keep fit/Gymnastics/Dance for Fitness*, Yoga/Pilates˅, Aquarobics*, Circuit training*, Skipping^

Team sports
Football/Rugby^, Basketball*, Netball*, Cricket, Rounders, Curling, Hockey^, Rowing*, Volleyball*, Shinty^

Non-team sports
Badminton/Tennis*, Squash^, Martial arts including Tai Chi*, Golf, Bowls, Archery, Croquet, Swing ball, Table tennis, Boxing*, Kick boxing^, Athletics*

Outdoor pursuit
Water skiing, Skiing/Snowboarding*, Horse Riding*, Canoeing/Kayaking*, Climbing*, Hillwalking/Rambling*, Hang-gliding/Parachuting, Orienteering^, Skateboarding/Inline skating*, Rollerblading*, Sailing/Windsurfing*, Surfboarding/Bodyboarding

Leisure pursuit
Swimming, Dancing*, Drumming, Fishing/Angling˅, Ice skating*, Motor Sports, Powerboating/Jetskiing*, Subaqua^

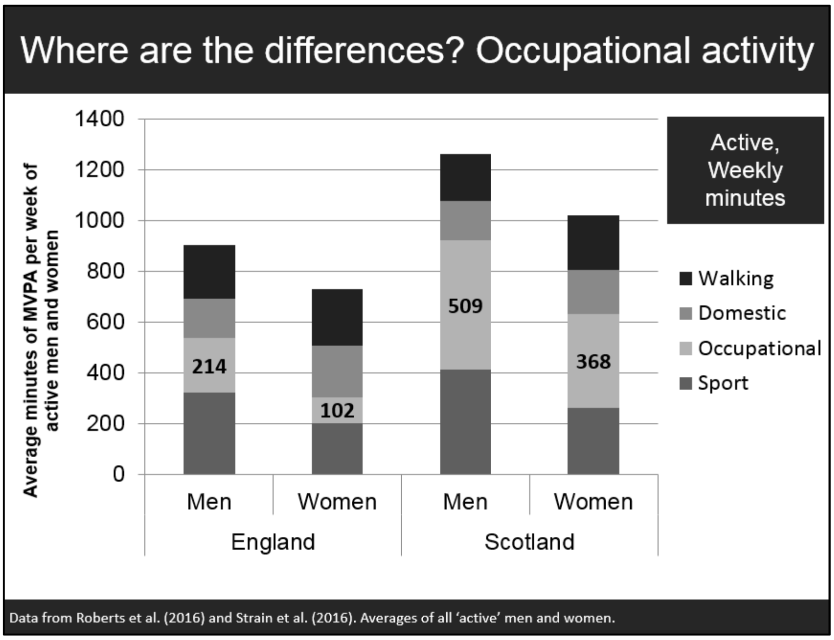
Cycling
Cycling*

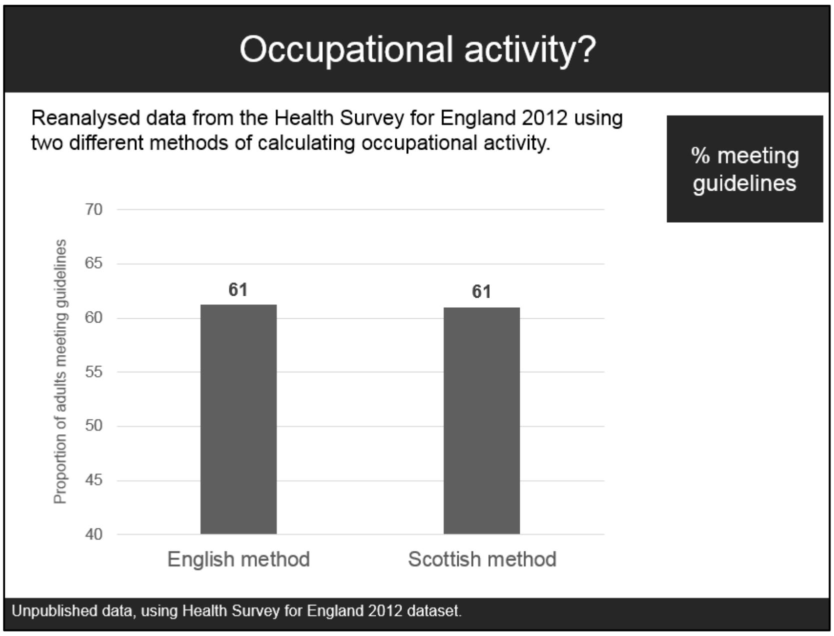
The additional question to determine intensity level was:
During the past four weeks, was the effort of [*activity name*] usually enough to make you breathe faster, feel warmer, or sweat? Yes/No

The intensities of the activities were calculated accordingly:
^There activities were always counted as vigorous intensity.
*These activities were counted as vigorous intensity the response to the additional question was ‘yes’. They were counted as moderate if the response was ‘no’.
˅These activities were counted as moderate intensity if the response to the additional question was ‘yes’. They were counted as light intensity (i.e. not included in analysis) if the response was ‘no’.
All other activities were always counted as moderate intensity.

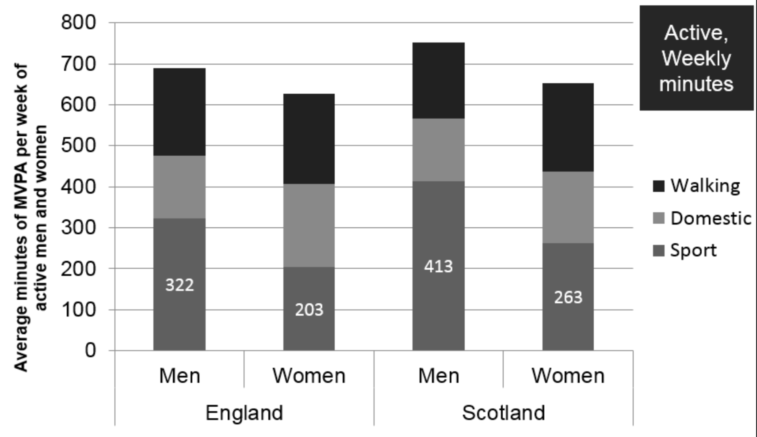
11. HEPA Europe analysis on differences between Scotland and England

This is a summary of additional analysis undertaken for a presentation to the HEPA Europe conference, Belfast, September 2016. The purpose of the additional analyses was to demonstrate that small differences between the HSE and SHeS questionnaire could explain the difference in prevalence figures between the nations (England 2012: 61%, Scotland 2013: 64%).





Is there a real difference in the sport and exercise domain?

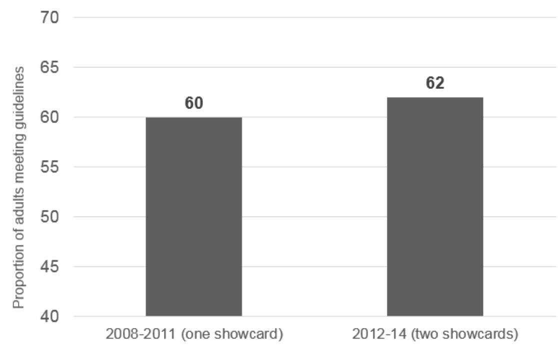


Data from Roberts et al. (2016) and Strain et al. (2016). Averages of all 'active' men and women.

Consistent prompting matters

Reanalysed data from the SHeS 2012-14 to test the effect of the additional showcard prompting.

% meeting guidelines



Using almost comparable methods for all other domains

Unpublished data, Scottish Health Survey 2008-11 and 2012-14 datasets

Consistent prompting matters

Proportion of adults undertaking sport in last 28 days	2008-11 SHeS (one showcard)	2013 SHeS (two showcards)	% change
Sports added to the second showcard			
Golf	3.9%	5.4%	38%
Bowls	1.2%	1.9%	58%
Hill walking/ hiking/rambling	0.2%	9.4%	4600%
Sports on the original showcard			
Running/jogging	11.2%	12.7%	13%
Swimming	12.9%	14.3%	11%
Football/Rugby	6.7%	6.2%	-7%

12. Evidence to trace impact of Study 1

The table below details how I have traced the impact of Study 1 as described in Figure 11.

Evidence description	Dates	Individuals involved and links to evidence where appropriate
Included as part of the Physical Activity for Health Research Centre's submission to Scottish Parliament inquiry on 'Tackling Obesity'	Dec 2016	Submission available http://www.parliament.scot/S5_HealthandSportCommittee/Inquiries/PAHRC.pdf
Presentation of findings to the National Steering Group Evidence Sub-group for Physical Activity, the Minister for Public Health and Sport, and the Chief Medical Officer in Scotland	Feb 2016 – Jun 2017	Professor Nanette Mutrie MBE, personal communications
Discussion of findings with the Chief Medical Officer in Scotland and the Minister for Public Health and Sport	Feb 2016 – ongoing	Dr Andrew Murray, personal communication
Included as part of Physical Activity for Health Research Centre's evidence submission to the Health and Sport Committee inquiry into Sport Participation in Scotland	Jan 2017	Submission available http://www.parliament.scot/S5_HealthandSportCommittee/Inquiries/Physical_Activity_for_Health_Research_Centre.pdf
Presentation to Health and Social Care Analysts at the Scottish Government	Jun 2016	Presentation available on request
Press coverage	Feb 2016	Coverage in print editions of The Times, the Daily Mail, i, The Herald, The Scotsman, and many online news outlets. Clippings available on request.
Dumfries and Galloway local authority came across findings in media (although already a collaborator with others in Physical Activity for Health Research Centre). They are using the paper, along with Studies 2 and 3, to identify key investment priorities.	2016 onwards	Christopher Topping, Health and Well-being Specialist, Dumfries and Galloway, personal communication

Contacted by Edinburgh Leisure requesting link to Study 1 after media coverage. In communication a year later, they noted the work had been influential when testing/piloting interventions to support the insufficiently active to become active. They were interested whether age- or ability-related services were needed. They piloted three classes “Active sit”, “Strength and Balance”, and “Strength and cardio”.	Dec 2016	Helen Macfarlane, Head of Active Communities, Edinburgh Leisure, personal communication
Contacted by National Health Service Health Scotland about Study 1 after media coverage to see if we had undertaken further work relating to walking and obesity in the insufficiently active. We sent a short evidence summary of the contribution walking could make to “low active” adults including results of Study 1. We subsequently met, during which we discussed the findings of a BMedSci student dissertation that had replicated Study 1’s methods, replacing age with obesity status. We also discussed the potential role of SB to obesity levels. In communication a year later, they informed us that the information we had provided at that meeting had shaped how they support the Scottish Government in obesity-related policies.	Aug 2016	Deborah Shipton, Public Health Advisor (Evaluation) National Health Service Health Scotland, personal communication. Evidence summary included after this table. Meeting notes and BMedSci dissertation available on request.
Study 1’s findings included in teaching materials on course at University of Edinburgh: MSc Physical Activity for Health, BSc Applied Sports Science, BMedSci Intercalated Medical degree, and on MA Physical Education. Also included as part of resources for all University of Edinburgh medical students to access.	Sept 2015 onwards	Lecture materials available on request.

Poster presentation at British Association for Sport and Exercise Sciences conference	Dec 2015	Abstract available here http://www.tandfonline.com/doi/full/10.1080/02640414.2015.1110333
Roberts et al. (2016) developed on the method of Study 1 (Professor Charlie Foster and Dr Nick Townsend co-authors on both papers).	2016	Full reference: Roberts, D., Townsend, N., & Foster, C. (2016). Use of new guidance to profile 'equivalent minutes' of aerobic physical activity for adults in England reveals gender, geographical, and socio-economic inequalities in meeting public health guidance: A cross-sectional study. *Preventive Medicine Reports, 4*, 50-60. doi: 10.1016/j.pmedr.2016.05.009
Contributed to symposium on domain-specific aerobic physical activity amongst U.K. home nations. Presented Study 1's findings (Dr Paul Kelly), symposium discussant (Tessa Strain).	Sept 2016	Presentations available on Open Science Framework https://osf.io/xkwrq/ and https://osf.io/sq3nc/
Cited in evidence review for Outcome 2 on the Active Scotland Outcomes Framework in support of considering age and sex-related differences in moderate-to-vigorous physical activity behaviours.	Jun 2016	Report available http://www.gov.scot/Resource/0050/00501863.docx
The Physical Activity for Health Research Centre named as stakeholder that can provide relevant research relating to 'Let's get Scotland Walking' (The National Walking Strategy) action plan.		Detailed action plan available at http://www.paha.org.uk/File/Index/180e8cb3-aeaf-4eb4-960a-a5d900f880e1
Paper cited in Public Health England report: "10 minutes brisk walking each day in mid-life for health benefits and towards achieving physical activity recommendations".		Report available https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/639030/Health_benefits_of_10_mins_brisk_walking_evidence_summary.pdf

13. Supplementary tables from Study 2

These tables were included as supplementary materials in the published article Strain, T., Fitzsimons, C.F., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. BMC Public Health, 16, 1108. Tables have been split to aid legibility.

Supplementary Table 1. The Results from Multiple Logistic Regression Investigating the Effect of Age-group, Gender, and their Interaction on Participation Levels

	Proportion meeting the muscle strengthening guidelines					
	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003
Age group						
16-24				reference category		
25-34	-0.47	0.13	-3.57	0.000	*-0.72, -0.21*	*
35-44	-0.95	0.13	-7.21	0.000	*-1.21, -0.69*	*
45-54	-1.15	0.13	-8.77	0.000	*-1.41, -0.89*	*
55-64	-1.69	0.14	-12.31	0.000	*-1.96, -1.42*	*
65-74	-2.11	0.14	-14.82	0.000	*-2.39, -1.83*	*
75+	-2.54	0.18	-13.97	0.000	*-2.89, -2.18*	*
Sex						
Male				reference category		
Female	-0.74	0.14	-5.29	0.000	*-1.01, -0.46*	*
Interaction						
Female*25-34	0.27	0.17	1.54	0.123	*-0.07, 0.61*	
Female*35-44	0.67	0.17	3.90	0.000	*0.34, 1.01*	*
Female*45-54	0.44	0.17	2.51	0.012	*0.10, 0.78*	
Female*55-64	0.53	0.18	2.94	0.003	*0.18, 0.89*	
Female*65-74	0.60	0.20	3.03	0.003	*0.21, 1.00*	
Female*75+	-0.17	0.24	-0.68	0.499	*-0.65, 0.31*	

	Proportion undertaking some muscle strengthening activities					
	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003
Age group						
16-24				reference category		
25-34	0.34	0.16	2.10	0.036	*0.02, 0.65*	
35-44	0.27	0.15	1.77	0.077	*-0.03, 0.57*	
45-54	0.20	0.15	1.39	0.166	*-0.08, 0.49*	
55-64	-0.02	0.16	-0.15	0.884	*-0.33, 0.28*	
65-74	-0.51	0.16	-3.13	0.002	*-0.82, -0.19*	
75+	-1.08	0.21	-5.14	0.000	*-1.50, -0.67*	*
Sex						
Male				reference category		
Female	0.61	0.16	3.91	0.000	*0.31, 0.92*	*
Interaction						
Female*25-34	-0.52	0.20	-2.59	0.010	*-0.92, -0.13*	
Female*35-44	-0.65	0.20	-3.30	0.001	*-1.03, -0.26*	
Female*45-54	-0.62	0.18	-3.39	0.001	*-0.98, -0.26*	
Female*55-64	-0.71	0.19	-3.76	0.000	*-1.09, -0.34*	*
Female*65-74	-0.56	0.20	-2.76	0.006	*-0.96, -0.16*	
Female*75+	-0.81	0.28	-2.91	0.004	*-1.35, -0.26*	

	Proportion undertaking no muscle strengthening activities					
	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003
Age group						
16-24				reference category		
25-34	0.30	0.14	2.14	0.033	*0.03, 0.58*	
35-44	0.84	0.14	6.10	0.000	*0.57, 1.11*	*
45-54	1.06	0.14	7.64	0.000	*0.78, 1.33*	*
55-64	1.60	0.14	11.38	0.000	*1.33, 1.88*	*
65-74	2.15	0.14	15.48	0.000	*1.87, 2.42*	*
75+	2.70	0.17	16.23	0.000	*2.38, 3.03*	*
Sex						
Male				reference category		
Female	0.37	0.15	2.47	0.014	*0.08, 0.66*	
Interaction						
Female*25-34	0.04	0.18	0.23	0.816	*-0.32, 0.40*	
Female*35-44	-0.29	0.17	-1.66	0.097	*-0.63, 0.05*	
Female*45-54	-0.13	0.18	-0.73	0.466	*-0.47, 0.22*	
Female*55-64	-0.17	0.17	-1.00	0.319	*-0.51, 0.17*	
Female*65-74	-0.31	0.18	-1.75	0.081	*-0.67, 0.04*	
Female*75+	0.22	0.21	1.07	0.284	*-0.19, 0.63*	

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design.

Supplementary Table 2. The Results from Simple Logistic Regression Investigating the Effect of Age-group on Participation in Specific Muscle Strengthening Sport and Exercise Activities, Stratified by Gender (weighted n=6873 men, 7459 women).

	Proportion of men participating in muscle strengthening activity					
Age group	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni -adjusted α=0.0003
Workout at gym						
16-24			reference category			
25-34	-0.31	0.13	-2.36	0.019	-0.58, -0.05	
35-44	-0.96	0.14	-6.76	0.000	-1.23, -0.68	*
45-54	-1.09	0.13	-8.11	0.000	-1.35, -0.82	*
55-64	-1.74	0.16	-10.78	0.000	-2.05, -1.42	*
65-74	-2.22	0.17	-12.98	0.000	-2.56, -1.89	*
75+	-2.81	0.26	-10.75	0.000	-3.32, -2.29	*
Exercises						
16-24			reference category			
25-34	-0.32	0.15	-2.20	0.028	-0.60, -0.03	
35-44	-0.97	0.16	-6.09	0.000	-1.28, -0.66	*
45-54	-1.43	0.18	-8.01	0.000	-1.78, -1.08	*
55-64	-1.84	0.18	-10.33	0.000	-2.20, -1.49	*
65-74	-2.35	0.21	-11.22	0.000	-2.76, -1.94	*
75+	-2.71	0.29	-9.34	0.000	-3.28, -2.14	*
Running						
16-24			reference category			
25-34	-0.35	0.15	-2.31	0.021	-0.64, -0.05	
35-44	-0.93	0.16	-5.82	0.000	-1.25, -0.62	*
45-54	-1.36	0.16	-8.4	0.000	-1.68, -1.04	*
55-64	-2.76	0.24	-11.56	0.000	-3.23, -2.29	*
65-74	-3.43	0.29	-11.83	0.000	-4.00, -2.86	*
75+	-5.98	1.01	-5.91	0.000	-7.96, -3.99	*
Swimming						
16-24			reference category			
25-34	0.35	0.19	1.79	0.073	-0.03, 0.73	
35-44	0.29	0.19	1.53	0.126	-0.08, 0.66	
45-54	0.06	0.18	0.30	0.762	-0.30, 0.41	
55-64	-0.45	0.20	-2.24	0.025	-0.84, -0.06	
65-74	-0.80	0.21	-3.90	0.000	-1.21, -0.40	*
75+	-1.38	0.27	-5.12	0.000	-1.91, -0.85	*

Hill walking						
16-24			reference category			
25-34	0.26	0.26	1.03	0.304	-0.24, 0.77	
35-44	0.01	0.26	0.02	0.981	-0.50, 0.51	
45-54	0.48	0.25	1.96	0.050	0.00, 0.97	
55-64	0.23	0.25	0.93	0.355	-0.26, 0.73	
65-74	-0.21	0.27	-0.80	0.422	-0.73, 0.31	
75+	-1.27	0.37	-3.44	0.001	-2.00, -0.55	
Football/Rugby						
16-24			reference category			
25-34	-0.70	0.15	-4.54	0.000	-1.00, -0.40	*
35-44	-1.33	0.17	-7.86	0.000	-1.66, -0.99	*
45-54	-1.95	0.19	-10.36	0.000	-2.32, -1.58	*
55-64	-3.00	0.27	-10.94	0.000	-3.54, -2.47	*
65-74	-5.11	0.60	-8.54	0.000	-6.28, -3.94	*
75+	-	-	-	-	-	
Cycling						
16-24			reference category			
25-34	0.00	0.18	0.02	0.985	-0.35, 0.36	
35-44	0.10	0.18	0.59	0.558	-0.24, 0.45	
45-54	0.00	0.17	0.02	0.986	-0.32, 0.33	
55-64	-0.76	0.19	-3.90	0.000	-1.14, -0.38	*
65-74	-1.75	0.24	-7.20	0.000	-2.22, -1.27	*
75+	-2.53	0.41	-6.14	0.000	-3.33, -1.72	*
Golf						
16-24			reference category			
25-34	1.63	0.54	3.02	0.003	0.57, 2.70	
35-44	1.47	0.52	2.84	0.005	0.45, 2.48	
45-54	1.89	0.50	3.77	0.000	0.91, 2.87	*
55-64	2.19	0.48	4.59	0.000	1.26, 3.13	*
65-74	1.92	0.49	3.93	0.000	0.96, 2.87	*
75+	1.64	0.52	3.14	0.002	0.62, 2.67	
Dance						
16-24						
25-34						
35-44						
45-54				N/A		
55-64						
65-74						
75+						
Aerobics						
16-24						
25-34						
35-44						
45-54				N/A		
55-64						
65-74						
75+						

	Proportion of women participating in muscle strengthening activity					
Age group	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni -adjusted α=0.0003
Workout at gym						
16-24			reference category			
25-34	-0.28	0.14	-2.01	0.045	-0.55, -0.01	
35-44	-0.48	0.13	-3.56	0.000	-0.74, -0.21	*
45-54	-0.82	0.14	-5.81	0.000	-1.10, -0.54	*
55-64	-1.56	0.17	-9.46	0.000	-1.89, -1.24	*
65-74	-2.03	0.19	-10.60	0.000	-2.40, -1.65	*
75+	-4.06	0.48	-8.47	0.000	-5.00, -3.12	*
Exercises						
16-24			reference category			
25-34	-0.42	0.15	-2.84	0.005	-0.70, -0.13	
35-44	-0.65	0.14	-4.65	0.000	-0.92, -0.38	*
45-54	-1.20	0.15	-8.07	0.000	-1.50, -0.91	*
55-64	-1.94	0.19	-10.40	0.000	-2.30, -1.57	*
65-74	-2.23	0.21	-10.56	0.000	-2.65, -1.82	*
75+	-3.27	0.36	-9.18	0.000	-3.97, -2.57	*
Running						
16-24			reference category			
25-34	-0.15	0.15	-0.98	0.329	-0.45, 0.15	
35-44	-0.52	0.15	-3.54	0.000	-0.81, -0.23	*
45-54	-1.27	0.16	-7.74	0.000	-1.59, -0.94	*
55-64	-2.23	0.24	-9.45	0.000	-2.69, -1.76	*
65-74	-3.98	0.48	-8.23	0.000	-4.93, -3.03	*
75+	-5.86	1.01	-5.80	0.000	-7.85, -3.88	*
Swimming						
16-24			reference category			
25-34	0.05	0.14	0.38	0.705	-0.22, 0.33	
35-44	-0.04	0.14	-0.29	0.769	-0.30, 0.23	
45-54	-0.45	0.13	-3.36	0.001	-0.71, -0.19	
55-64	-0.66	0.14	-4.56	0.000	-0.94, -0.37	*
65-74	-1.08	0.16	-6.53	0.000	-1.40, -0.75	*
75+	-2.58	0.27	-9.58	0.000	-3.11, -2.05	*
Hill walking						
16-24			reference category			
25-34	0.33	0.26	1.29	0.196	-0.17, 0.83	
35-44	0.28	0.25	1.10	0.273	-0.22, 0.77	
45-54	0.34	0.22	1.53	0.127	-0.10, 0.78	
55-64	0.05	0.26	0.19	0.849	-0.46, 0.55	
65-74	-0.47	0.27	-1.71	0.087	-1.00, 0.07	
75+	-2.03	0.46	-4.46	0.000	-2.92, -1.14	*

Football/Rugby						
16-24						
25-34						
35-44						
45-54			N/A			
55-64						
65-74						
75+						
Cycling						
16-24						
25-34						
35-44						
45-54			N/A			
55-64						
65-74						
75+						
Golf						
16-24						
25-34						
35-44						
45-54			N/A			
55-64						
65-74						
75+						
Dance						
16-24			reference category			
25-34	-0.70	0.22	-3.21	0.001	-1.70, 0.15	
35-44	-1.08	0.24	-4.54	0.000	-1.81, 0.05	*
45-54	-1.40	0.25	-5.68	0.000	-2.72, -0.31	*
55-64	-1.25	0.24	-5.10	0.000	-3.17, -0.90	*
65-74	-1.16	0.25	-4.67	0.000	-2.02, -0.17	*
75+	-2.29	0.36	-6.42	0.000	-2.00, -0.01	*
Aerobics						
16-24			reference category			
25-34	0.26	0.16	1.60	0.111	-0.06, 0.57	
35-44	0.14	0.16	0.90	0.366	-0.16, 0.45	
45-54	-0.21	0.16	-1.34	0.182	-0.53, 0.10	
55-64	-0.81	0.18	-4.41	0.000	-1.17, -0.45	*
65-74	-0.96	0.20	-4.92	0.000	-1.35, -0.58	*
75+	-1.49	0.23	-6.47	0.000	-1.94, -1.04	*

Note. N/A = not applicable (sample sizes were too small to perform analyses)

Supplementary Table 3. The Results from Multiple Logistic Regression Investigating the Effect of Age-group, Gender, and their Interaction on Participation Levels of Balance & Co-ordination (weighted n=1347 men, 1687 women)

	Proportion meeting the balance & co-ordination guidelines					
	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003
Age group						
65-69				reference category		
70-74	-0.44	0.17	-2.62	0.009	-0.76, -0.11	
75-79	-0.43	0.19	-2.27	0.024	-0.80, -0.06	
80-84	-0.75	0.24	-3.14	0.002	-1.23, -0.28	
85+	-1.34	0.34	-3.98	0.000	-2.00, -0.68	*
Sex						
Male				reference category		
Female	-0.39	0.15	-2.63	0.009	-0.67, -0.10	
Interaction						
Female*70-74	0.01	0.25	0.03	0.973	-0.49, 0.50	
Female*75-79	-0.57	0.28	-2.03	0.043	-1.12, -0.02	
Female*80-84	-0.31	0.34	-0.9	0.366	-0.97, 0.36	
Female*85+	-0.99	0.58	-1.69	0.091	-2.14, 0.16	

	Proportion undertaking some balance & co-ordination activities						Proportion undertaking no balance & co-ordination activities					
	B-coefficient	Linearised standard error[a]	t	*p* value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003	B-coefficient	Linearised standard error[a]	t	p value	95% confidence interval	Significant Bonferroni-adjusted α=0.0003
Age group												
65-69			reference category									
70-74	-0.13	0.19	-0.66	0.509	-0.51, 0.25		0.39	0.14	2.71	0.007	0.11, 0.67	
75-79	-0.18	0.21	-0.86	0.392	-0.60, 0.24		0.41	0.15	2.65	0.008	0.11, 0.71	
80-84	-0.51	0.29	-1.78	0.076	-1.08, 0.05		0.80	0.20	4.00	0.000	0.41, 1.19	*
85+	-1.86	0.61	-3.03	0.002	-3.06, -0.66		1.72	0.31	5.6	0.000	1.12, 2.33	*
Sex												
Male			reference category									
Female	0.07	0.16	0.42	0.672	-0.24, 0.38		0.24	0.12	2.02	0.043	0.01, 0.47	
Interaction												
Female*70-74	-0.22	0.27	-0.83	0.409	-0.75, 0.30		0.09	0.20	0.44	0.662	-0.30, 0.47	
Female*75-79	-0.19	0.29	-0.64	0.523	-0.76, 0.39		0.37	0.21	1.73	0.083	-0.05, 0.79	
Female*80-84	-0.56	0.40	-1.40	0.163	-1.35, 0.23		0.43	0.27	1.58	0.114	-0.10, 0.96	
Female*85+	0.39	0.67	0.58	0.562	-0.92, 1.69		0.32	0.44	0.74	0.460	-0.53, 1.18	

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design.

14. Measurement of muscle strengthening activities in national surveys

Survey, country	Journal article references	Measurement method
National Health Interview Survey 1998-2008, U.S.	Carlson, Fulton, Schoenborn, and Loustalot (2010)	Respondent reports frequency of leisure-time activities undertaken to increase muscle strength over a time period of their choice (day, week, month, or year). Examples given are lifting weights or calisthenics.
National Health And Nutritional Examination Survey 2003-2004/2003-2006, U.S.	Dankel et al. (2016b) Dankel, Loenneke, and Loprinzi (2015)	Respondent asked to report the frequency of participation in any physical activities specifically designed to strengthen their muscles over the 30 days prior to interview. Examples given are lifting weight, push-ups or sit-ups.
National Nutrition and Physical Activity Survey 2011-2012, Australia	Bennie, Pedišić, van Uffelen, Gale, et al. (2016) Freeston et al. (2017)	Respondents were asked to report the frequency of any strength or toning activities undertaken in the week prior to interview. Examples given are lifting weights, pull-ups, push-ups, or sit ups.
Exercise, Recreation and Sport Survey 2001-2010, Australia	Bennie, Pedišić, van Uffelen, Charity, et al. (2016)	Derived from responses to nine muscle-strengthening activities as determined by the researchers: Calisthenics, Gymnasium Workouts, Military exercise, Prime movers (over 50s), Body building, Circuits, Power team, Weight training for fitness, Weightlifting (competition).
Scottish Health Survey, U.K.	Strain, Fitzsimons, Kelly, et al. (2016)	Derived from responses to 40 sport and exercise activities determined by a panel of experts.
Regional Health and Well-being Study, Finland	Bennie et al. (2017)	Asked to report days and total time spent undertaking neuromuscular training (for example keep-fit circuit training or muscle strength training in a gym, and including exercises for the main muscle groups with 8-12 repetitions).

Note. Full references are in main thesis reference list.

15. Evidence to trace the impact of Study 2

The table below details how I have traced the impact of Study 2 as described in Figure 12.

Evidence description	Dates	Individuals involved and/or links to evidence where appropriate
Sent a lay summary of Study 2 to head of physical activity policy in the Scottish Government. This resulted in a meeting with the analyst with responsibility for physical activity and the development of a proposal to include indicators for muscle strengthening and balance and co-ordination activities (and sedentary time) on the Active Scotland Outcomes Framework.	Nov 2016 – Feb 2017	See Appendix 17 for lay summary and Appendix 18 for proposal.
Press coverage	Oct 2016	Coverage in print editions of The Times, The Sun, The Metro, The Herald, The Scotsman, The Daily Record and many online news outlets. Clippings available on request. Radio interview on The John Beattie show on BBC Radio Scotland.
Presentation of findings to National Steering Group Evidence Sub-group for Physical Activity, the Minister for Public Health and Sport, and the Chief Medical Officer in Scotland.	Feb 2016 – Jun 2017	Professor Nanette Mutrie MBE, personal communications.
Discussion of findings with those responsible for Chief Medical Officers' physical activity guidelines and the Minister for Public Health and Sport.	Feb 2016 – ongoing	Dr Andrew Murray, personal communication.
Results were shared with Professor Charlie Foster (who is chairing the update of the U.K. physical activity guidelines). The paper was circulated to members of an Expert Group specifically convened on muscle and bone strength and balance.	Nov 2017 - ongoing	Professor Charlie Foster, personal communication
When checking the derived MSA and BCA variables I noticed an error in the archived datasets. I communicated with ScotCen and the Scottish Government to make sure this did not happen in future and that the archive versions were changed.	Jun 2015-2016	Details of error available on request.

16. Lay summary of Study 2 for the Scottish Government

16th November 2016

Dear Louise Unwin,

We are writing to inform you of the main findings of our recent paper "*The forgotten guidelines: cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland",* as they are relevant to the monitoring of physical activity levels in Scotland.

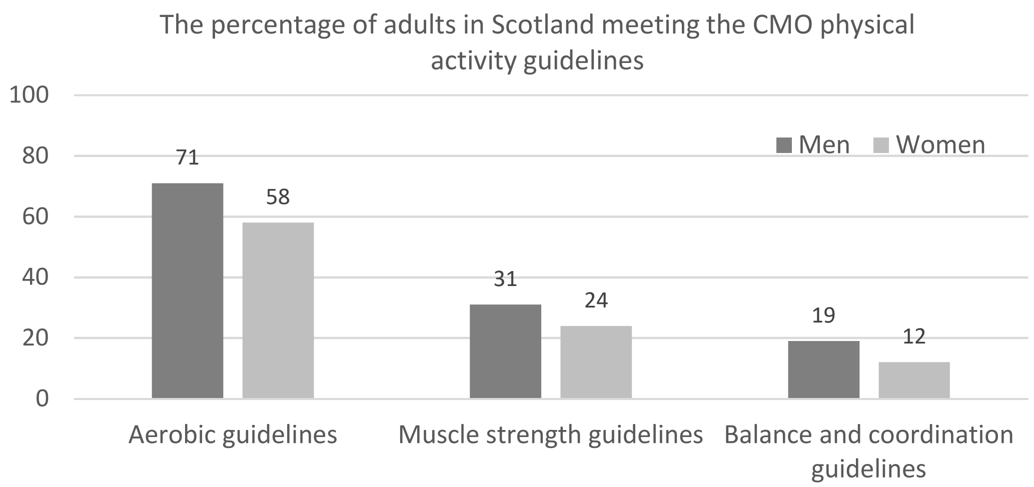
We have used Scottish Health Survey data to show that less than one-third of adults in Scotland are doing enough of the types of physical activity that develop the muscle, balance and coordination and that are needed for a healthy later life. Only 31% of men and 24% of women met the recommended muscle strengthening guidelines of two sessions of relevant activities per week. Among older adults (aged 65 and over), only 19% of men and 12% of women met similar guidelines for maintaining balance and coordination. These are significantly lower than the proportions meeting the aerobic activity guidelines (71% of men and 58% of women; see the chart at the end of this letter).

Higher levels of muscle strength are associated with a reduced risk of early death and heart disease, and improved metabolic control, independent of aerobic physical activity. Muscle strength is particularly important for older adults, along with balance and coordination, for reducing the risk of falls and associated complications.

We believe that including indicators relating to the muscle strengthening and balance and coordination guidelines in the Active Scotland Outcomes Framework is an important first step in addressing the low compliance with these guidelines. Few countries worldwide acknowledge these guidelines in their physical activity policies and so this would be another example of how Scotland is leading the way. We are planning future research to develop standardised methods of measuring compliance with these guidelines which would assist this process. We would like to offer our support to the Active Scotland Division, should you decide to take this issue forward.

Yours sincerely,

Tessa Strain (on behalf of the authors)



17. Proposal to add indicators to the Active Scotland Outcomes Framework

By Tessa Strain, Claire Fitzsimons, Paul Kelly, and Nanette Mutrie
Physical Activity for Health Research Centre, University of Edinburgh

Background

The main focus of physical activity (PA) strategies and policies over the last two decades, both globally and in Scotland, has been to increase the proportion of adults meeting the moderate-and-vigorous intensity aerobic PA (MVPA) guidelines. This situation remains the case, despite the Chief Medical Officers including statements on muscle strength (MS), balance and co-ordination (BC) and sedentary time in their 2011 update to the U.K. PA guidelines and in a widely disseminated infographic (Department of Health, 2011; Reid & Foster, 2016). These additions were made based on the latest available evidence suggesting that MS, BC, and sedentary time could all influence health 'independently' of MVPA levels.

Briefly, increased MS can reduce the risk of many chronic diseases such as cardiovascular diseases and diabetes mainly through changes to muscle and bone tissue (Dankel et al., 2015). This applies to all ages, but is specifically pertinent to older adults as the natural age-related decline in muscle mass (sarcopenia) and bone mass (often leading to osteoporosis) accelerates from age 50 (Mitchell et al., 2012; Montero-Fernandez & Serra-Rexach, 2013). Without intervention, many people drop below the threshold levels of strength required to be functionally independent. Loss of strength also increases the risk of falling, and low bone mass increases the risk of severe complications after a fall. This is where BC activities are also relevant, as they have been shown to be effective at reducing the risk of falls (Gillespie et al., 2012).

Recent literature shows that excessive time spent in sedentary behaviours (sitting or lying down undertaking activities with a low energy requirement) is associated with an increased risk of all-cause mortality, cardiovascular diseases, diabetes, and some cancers (Biswas et al., 2015). This relationship persists after adjusting for MVPA levels in all but the very active (significantly above the recommended levels) (Ekelund et al., 2016).

In this document we set out our proposal to add indicators relating to these guidelines to the Active Scotland Outcomes Framework. This would make them a priority alongside MVPA levels, helping to raise awareness, and potentially allowing time, resources, and efforts to be directed towards promoting relevant activities amongst adults in Scotland. This would subsequently benefit population health. We acknowledge that there are concerns around the current measurement methods for these indicators and that the evidence is evolving rapidly. However, we believe it is worth introducing these indicators at this stage to make a statement of intent towards addressing these health behaviours.

Suggested additional indicators

To be added under “Vision: A more active Scotland”

- The proportion of adults (aged ≥16 years) who meet the MS guidelines of at least 2 relevant sessions per week.
- The proportion of adults (aged ≥16 years) who report being sedentary for more than 8 hours on an average day.

To be added under “Outcome 1: We encourage and enable the inactive to be more active”

- The proportion of older adults (aged ≥50 years) who do not meet the MS guidelines of at least 2 relevant sessions per week.
- The proportion of older adults (aged ≥65 years) who do not meet the BC guidelines of at least 2 relevant sessions per week.

All data required to monitor these indicators have been collected annually by the Scottish Health Survey since 2012, allowing the establishment of 4 year trend data immediately.

Justification for and further information on the suggested additional indicators

We have suggested the indicators for MS and sedentary time that apply to all adults should sit alongside the MVPA guideline as a top priority. They are based on the statements in the 2011 Chief Medical Officers’ guidelines and apply to the whole population (Department of Health, 2011).

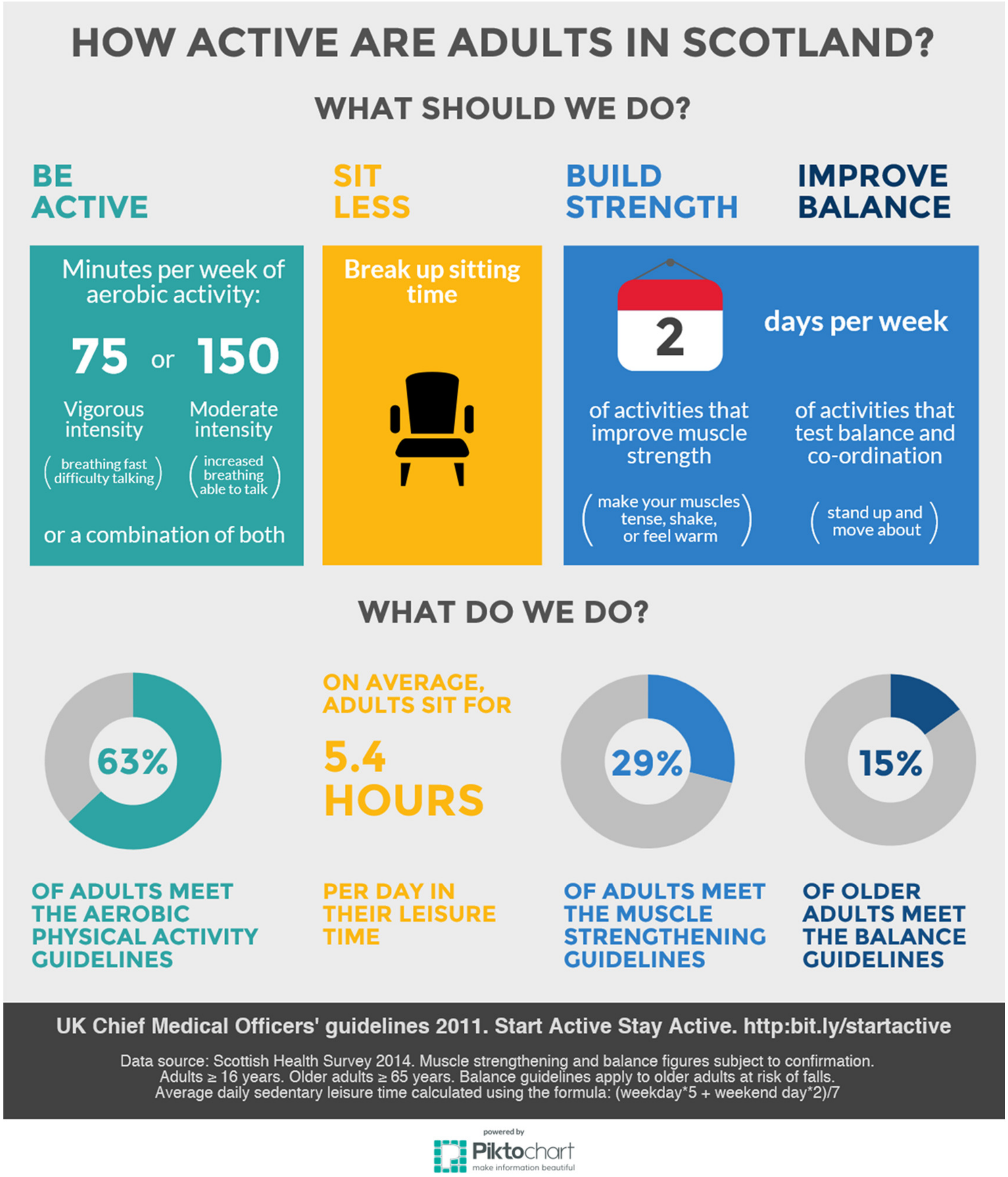
We have suggested that the indicators relating to older adults (for MS and BC) are included under Outcome 1 as they relate to inactive groups of the population.

The data relating to the MS and BC indicators are already routinely collected and analysed in such a way that creating these indicators would be straightforward. The sedentary time data would require a different analytical approach in order to create this indicator. We have done some work towards this, the results of which are in a recently submitted journal article. Briefly, we propose that the measure of sedentary time at work is added to the total for weekday leisure sedentary time that is already reported. We then propose that this new total is combined with the weekend day total (already reported) to give an overall ‘typical day’, using a weighting of 5 weekdays to 2 weekend days. Finally, we suggest that a cut off of 8 hours is applied to the data so that the indicator reports the proportion of adults exceeding that amount on a typical day. The 2011 Chief Medical Officers’ guidelines do not themselves suggest a cut-off time, but the latest available evidence suggests that there is a significant increased risk of premature mortality for those that sit over 8 hours (with the possible exception of a minority that undertake very high levels of MVPA) (Chau et al., 2013; Ekelund et al., 2016).

All references included in thesis reference list except for:

Mitchell, W.K., et al., *Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review.* Frontiers in Physiology, 2012. **3**: p. 260.

18. Infographic produced while on internship at the Scottish Government



19. Supplementary Tables from Study 3

Supplementary Table 1. Output from Linear Regressions on Total and Behaviour-specific Weekday Sedentary Time, for all Adults and Stratified by Work Status

	All adults			Adults in work					
	Total weekday sedentary time			Total weekday sedentary time			Sitting time at work		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex									
Men	reference category			reference category			reference category		
Women	-0.0	-0.3, 0.3	0.854	-0.4	-1.1, 0.3	0.226	-0.4	-1.0, 0.2	0.167
Age									
16-24	-0.8	-1.2, -0.4	<0.001	-0.9	-1.5, -0.3	0.003	-0.9	-1.4, -0.4	<0.001
25-34	0.3	-0.1, 0.7	0.111	0.0	-0.5, 0.6	0.897	0.7	0.2, 1.2	0.006
35-44	0.2	-0.1, 0.6	0.183	-0.1	-0.6, 0.4	0.755	1.0	0.5, 1.4	<0.001
45-54	0.4	0.1, 0.7	0.007	0.1	-0.4, 0.6	0.702	0.9	0.4, 1.3	<0.001
55-64	0.3	-0.0, 0.6	0.086	0.1	-0.4, 0.6	0.618	0.6	0.1, 1.1	0.010
65-74	-0.2	-0.5, 0.1	0.202	reference category			reference category		
75+	reference category			-1.3	-2.7, 0.1	0.075	-1.1	-2.0, -0.1	0.028
Interaction									
Female#16-24	0.1	-0.4, 0.6	0.776	0.4	-0.5, 1.3	0.378	0.5	-0.2, 1.2	0.174
Female#25-34	-0.9	-1.4, -0.5	<0.001	-0.0	-0.8, 0.8	0.968	0.2	-0.5, 0.9	0.581
Female#35-44	-0.8	-1.2, -0.4	<0.001	0.1	-0.7, 0.9	0.844	0.1	-0.5, 0.7	0.719
Female#45-54	-0.9	-1.3, -0.5	<0.001	-0.4	-1.1, 0.4	0.301	-0.3	-0.9, 0.3	0.362
Female#55-64	-0.8	-1.2, -0.5	<0.001	-0.3	-1.1, 0.5	0.478	-0.2	-0.9, 0.4	0.517
Female#65-74	-0.4	-0.8, -0.0	0.032	reference category			reference category		
Female#75+	reference category			0.4	-1.6, 2.5	0.675	0.7	-0.6, 2.1	0.277
Model constant	7.4	7.2, 7.6	<0.001	7.7	7.3, 8.2	<0.001	2.9	2.5, 3.3	<0.001

	Adults in work					
	TV/Screen sedentary time			Other leisure sedentary time		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex						
Men	reference category			reference category		
Women	-0.1	-0.5, 0.3	0.699	0.0	-0.2, 0.3	0.744
Age						
16-24	0.1	-0.3, 0.5	0.614	-0.1	-0.3, 0.1	0.495
25-34	-0.4	-0.7, -0.1	0.005	-0.2	-0.4, -0.0	0.012
35-44	-0.7	-1.0, -0.5	<0.001	-0.3	-0.5, -0.2	<0.001
45-54	-0.5	-0.8, -0.2	<0.001	-0.3	-0.4, -0.1	<0.001
55-64	-0.3	-0.6, -0.1	0.012	-0.1	-0.3, 0.0	0.155
65-74	reference category			reference category		
75+	-0.8	-1.4, -0.2	0.005	0.6	(0.1, 1.1	0.018
Interaction						
Female#16-24	-0.4	-0.9, 0.1	0.142	0.3	-0.0, 0.6	0.069
Female#25-34	-0.3	-0.7, 0.1	0.157	0.1	-0.2, 0.4	0.499
Female#35-44	-0.1	-0.5, 0.3	0.766	0.0	-0.3, 0.3	0.864
Female#45-54	-0.1	-0.5, 0.3	0.496	0.0	-0.3, 0.3	0.825
Female#55-64	-0.2	-0.6, 0.3	0.471	0.1	-0.2, 0.4	0.601
Female#65-74	reference category			reference category		
Female#75+	0.3	-0.7, 1.3	0.613	-0.6	-1.5, 0.4	0.236
Model constant	3.2	3.0, 3.5	<0.001	1.6	1.5, 1.8	<0.001

reference category

	Adults not in work								
	Total weekday sedentary time			Total weekday sedentary time			Sitting time at work		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex									
Men	reference category			reference category			reference category		
Women	-0.0	-0.3, 0.2	0.764	0.0	-0.2, 0.3	0.728	-0.1	-0.3, 0.1	0.404
Age									
16-24	-1.2	-1.6, -0.7	<0.001	0.2	-0.2, 0.6	0.323	-1.4	-1.6, -1.1	<0.001
25-34	-0.1	-0.8, 0.5	0.691	0.6	-0.0, 1.2	0.061	-0.7	-1.2, -0.3	0.002
35-44	-0.1	-0.8, 0.6	0.851	0.7	0.1, 1.4	0.031	-0.8	-1.1, -0.4	<0.001
45-54	0.3	-0.2, 0.9	0.277	1.0	0.5, 1.5	<0.001	-0.7	-1.0, -0.4	<0.001
55-64	-0.1	-0.5, 0.3	0.57	0.7	0.3, 1.1	<0.001	-0.8	-1.1, -0.6	<0.001
65-74	-0.3	-0.6, -0.0	0.042	0.2	-0.0, 0.5	0.085	-0.6	-0.8, -0.3	<0.001
75+	reference category			reference category			reference category		
Interaction									
Female#16-24	0.1	-0.5, 0.8	0.668	-0.6	-1.1, -0.0	0.048	0.7	0.3, 1.0	<0.001
Female#25-34	-2.0	-2.8, -1.2	<0.001	-1.8	-2.4, -1.1	<0.001	-0.2	-0.7, 0.3	0.392
Female#35-44	-1.9	-2.7, -1.1	<0.001	-1.6	-2.4, -0.9	<0.001	-0.3	-0.7, 0.1	0.179
Female#45-54	-1.2	-1.9, -0.6	<0.001	-1.2	-1.7, -0.6	<0.001	-0.0	-0.4, 0.3	0.831
Female#55-64	-0.8	-1.2, -0.3	0.001	-0.9	-1.4, -0.5	<0.001	0.2	-0.1, 0.5	0.301
Female#65-74	-0.3	-0.7, 0.0	0.087	-0.5	-0.8, -0.1	0.009	0.1	-0.1, 0.4	0.387
Female#75+	reference category			reference category			reference category		
Model constant	7.4	7.2, 7.7	<0.001	4.3	4.1, 4.5	<0.001	3.1	2.9, 3.3	<0.001

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design. CI=confidence interval.

Supplementary Table 2. Output from Linear Regressions on Total and Behaviour-specific Weekend Day Sedentary Time, for all Adults

	Total weekend sedentary time			TV/Screen sedentary time			Other leisure sedentary time		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex									
Men		reference category			reference category			reference category	
Women	-0.2	-0.5, 0.1	0.277	-0.1	-0.4, 0.2	0.497	-0.1	-0.3, 0.1	0.504
Age									
16-24	-1.3	-1.7, -0.9	<0.001	-0.0	-0.4, 0.3	0.81	-1.2	-1.5, -1.0	<0.001
25-34	-1.7	-2.1, -1.4	<0.001	-0.6	-0.9, -0.3	<0.001	-1.2	-1.4, -1.0	<0.001
35-44	-1.9	-2.2, -1.6	<0.001	-0.6	-0.9, -0.4	<0.001	-1.3	-1.5, -1.1	<0.001
45-54	-1.7	-2.0, -1.4	<0.001	-0.5	-0.7, -0.2	0.001	-1.2	-1.4, -1.0	<0.001
55-64	-1.3	-1.6, -1.0	<0.001	-0.2	-0.5, 0.1	0.144	-1.1	-1.3, -0.9	<0.001
65-74	-0.5	-0.8, -0.2	0.001	0.1	-0.2, 0.3	0.559	-0.6	-0.8, -0.4	<0.001
75+		reference category			reference category			reference category	
Interaction									
Female#16-24	-0.2	-0.6, 0.3	0.516	-0.7	-1.1, -0.3	0.001	0.5	0.2, 0.8	0.001
Female#25-34	-0.3	-0.7, 0.1	0.154	-0.5	-0.8, -0.1	0.008	0.2	-0.1, 0.4	0.172
Female#35-44	-0.2	-0.6, 0.2	0.258	-0.4	-0.7, -0.1	0.012	0.2	-0.0, 0.4	0.103
Female#45-54	-0.1	-0.5, 0.3	0.548	-0.3	-0.6, 0.0	0.051	0.2	-0.0, 0.4	0.092
Female#55-64	-0.2	-0.5, 0.2	0.368	-0.4	-0.8, -0.1	0.008	0.3	0.0, 0.5	0.025
Female#65-74	-0.2	-0.6, 0.2	0.252	-0.3	-0.7, -0.0	0.048	0.1	-0.2, 0.4	0.428
Female#75+	reference category				reference category			reference category	
Model constant	7.4	7.2, 7.7	<0.001	4.2	4, 4.5	<0.001	3.2	3.0, 3.4	<0.001

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design. CI=confidence interval

Supplementary Table 3. Mean and 95% Confidence Intervals of the Relative Contributions of the Categories of Behaviours to Total Weekday Sedentary Time, Stratified by Work Status, and to Total Weekend Day Sedentary Time, for all Adults

	Weekday										Weekend day			
	Adults in work						Adults not in work				All adults			
	ST at work (%)	95% CI[a]	TV/ Screen ST (%)	95% CI[a]	Other leisure ST (%)	95% CI[a]	TV/ Screen ST (%)	95% CI[a]	Other leisure ST (%)	95% CI[a]	TV/ Screen ST (%)	95% CI[a]	Other leisure ST (%)	95% CI[a]
Men														
16-24	24.9	21.8, 28.0	50.2	46.9, 53.5	24.9	22.9, 26.9	70.1	67.6, 72.6	29.9	27.4, 32.4	65.6	63.6, 67.6	34.4	32.4, 36.4
25-34	40.9	38.6, 43.2	38.9	37.0, 40.9	20.2	19.0, 21.4	66.4	62.1, 70.7	33.6	29.3, 37.9	63.3	61.8, 64.7	36.7	35.3, 38.2
35-44	44.6	42.5, 46.7	36.1	34.5, 37.6	19.4	18.2, 20.5	65.5	61.3, 69.7	34.5	30.3, 38.7	62.7	61.2, 64.1	37.3	35.9, 38.8
45-54	43.4	41.7, 45.2	37.6	36.2, 39.1	19.0	18.0, 19.9	66.3	63.2, 69.5	33.7	30.5, 36.8	64.0	62.8, 65.3	36.0	34.7, 37.2
55-64	39.7	37.8, 41.7	39.3	37.6, 40.9	21.0	19.8, 22.3	65.9	63.8, 68.0	34.1	32.0, 36.2	62.8	61.5, 64.1	37.2	35.9, 38.5
65-74	33.6	30.0, 37.2	44.4	41.1, 47.8	21.9	20.1, 23.8	62.6	61.1, 64.0	37.4	36.0, 38.9	61.1	59.8, 62.3	38.9	37.7, 40.2
75+	23.0	14.5, 31.6	40.8	32.6, 49.0	36.2	28.7, 43.6	57.1	55.4, 58.9	42.9	41.1, 44.6	56.0	54.3, 57.7	44.0	42.3, 45.7
Women														
16-24	24.9	22.2, 27.5	44.7	42.3, 47.1	30.4	28.5, 32.3	61.5	58.5, 64.4	38.5	35.6, 41.5	57.0	55.0, 59.0	43.0	41.0, 45.0
25-34	39.4	37.3, 41.4	37.1	35.4, 38.8	23.5	22.3, 24.8	60.4	57.7, 63.1	39.6	36.9, 42.3	58.6	57.3, 59.9	41.4	40.1, 42.7
35-44	43.4	41.6, 45.2	35.8	34.3, 37.3	20.8	19.9, 21.7	62.4	60.0, 64.9	37.6	35.1, 40.0	59.1	57.9, 60.3	40.9	39.7, 42.1
45-54	38.4	36.7, 40.0	39.4	38.0, 40.8	22.2	21.3, 23.2	63.5	61.1, 66.0	36.5	34.0, 38.9	60.4	59.3, 61.5	39.6	38.5, 40.7
55-64	35.2	33.1, 37.4	39.7	38.1, 41.4	25.1	23.7, 26.4	62.9	61.2, 64.6	37.1	35.4, 38.8	58.9	57.6, 60.2	41.1	39.8, 42.4
65-74	30.9	26.1, 35.7	44.4	40.7, 48.2	24.7	21.5, 27.8	60.8	59.7, 62.0	39.2	38.0, 40.3	58.9	57.7, 60.1	41.1	39.9, 42.3
75+	31.1	23.3, 38.9	40.9	33.7, 48.1	28.0	17.1, 38.9	57.8	56.3, 59.3	42.2	40.7, 43.7	55.9	54.4, 57.4	44.1	42.6, 45.6

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design. CI=confidence interval.

Supplementary Table 4. Output from Linear Regressions on Relative Contributions of the Categories of Behaviours to Total Weekday Sedentary Time, Stratified by Work Status, and to Total Weekend Day Sedentary Time, for all Adults

	Weekday sedentary time								
	Adults in work								
	Sitting at work			TV/Screen sedentary time			Other leisure sedentary time		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex									
Men		reference category			reference category			reference category	
Women	-2.7	-8.5, 3.0	0.356	-0.0	-4.8, 4.8	0.996	2.7	-0.8, 6.3	0.132
Age									
16-24	-8.7	-13.4, -4.0	<0.001	5.8	1.0, 10.6	0.018	2.9	0.2, 5.6	0.032
25-34	7.3	3.0, 11.6	0.001	-5.5	-9.4, -1.7	0.005	-1.8	-4.0, 0.5	0.124
35-44	11.0	6.9, 15.1	<0.001	-8.4	-12.1, -4.7	<0.001	-2.6	-4.7, -0.5	0.018
45-54	9.8	5.8, 13.8	<0.001	-6.8	-10.5, -3.2	<0.001	-3.0	-5.1, -0.9	0.005
55-64	6.1	2.0, 10.2	0.004	-5.2	-9.0, -1.4	0.007	-0.9	-3.1, 1.3	0.413
65-74		reference category			reference category			reference category	
75+	-10.6	-20.1, -1.1	0.029	-3.6	-12.5, 5.2	0.420	14.2	6.4, 22.0	<0.001
Interaction									
Female#16-24	2.7	-4.5, 9.8	0.463	-5.5	-11.9, 0.9	0.090	2.8	-1.7, 7.4	0.226
Female#25-34	1.2	-5.2, 7.6	0.715	-1.8	-7.1, 3.5	0.501	0.6	-3.3, 4.5	0.756
Female#35-44	1.5	-4.8, 7.8	0.635	-0.3	-5.3, 4.8	0.921	-1.3	-5.1, 2.6	0.518
Female#45-54	-2.4	-8.5, 3.8	0.452	1.8	-3.3, 6.9	0.484	0.5	-3.3, 4.4	0.783
Female#55-64	-1.8	-8.2, 4.7	0.590	0.5	-4.9, 5.8	0.865	1.3	-2.7, 5.3	0.518
Female#65-74		reference category			reference category			reference category	
Female#75+	10.8	-2.1, 23.7	0.100	0.1	-11.5, 11.8	0.985	-10.9	-24.9, 3.1	0.127
Model constant	33.6	30.0, 37.2	<0.001	44.4	41.1, 47.8	<0.001	21.9	20.1, 23.8	<0.001

	Weekday sedentary time			Weekend day sedentary time		
	Those not in work			All adults		
	TV/Screen sedentary time[b]			TV/Screen sedentary time[b]		
	B-coefficient	95% CI[a]	p-value	B-coefficient	95% CI[a]	p-value
Sex						
Men						
Women	0.6	1.1, 0.6	0.554	-0.1	-2.2, 2.0	0.932
Age						
16-24	13.0	1.6, 8.4	<0.001	9.6	6.9, 12.3	<0.001
25-34	9.2	2.4, 3.9	<0.001	7.3	5.0, 9.5	<0.001
35-44	8.4	2.3, 3.6	<0.001	6.6	4.5, 8.8	<0.001
45-54	9.2	1.8, 5.0	<0.001	8.0	5.9, 10.1	<0.001
55-64	8.8	1.4, 6.3	<0.001	6.8	4.6, 9.0	<0.001
65-74	5.4	1.1, 4.8	<0.001	5.1	3.0, 7.2	<0.001
75+	reference category			reference category		
Interaction						
Female#16-24	-9.3	2.2, -4.2	<0.001	-8.5	-12.0, -5.1	<0.001
Female#25-34	-6.6	2.6, -2.5	0.012	-4.6	-7.3, -1.9	0.001
Female#35-44	-3.7	2.7, -1.4	0.168	-3.5	-6.1, -0.8	0.010
Female#45-54	-3.4	2.2, -1.5	0.126	-3.5	-6.2, -0.9	0.009
Female#55-64	-3.6	1.7, -2.1	0.032	-3.8	-6.5, -1.1	0.006
Female#65-74	-2.4	1.4, -1.7	0.085	-2.1	-4.7, 0.5	0.120
Female#75+	reference category			reference category		
Model constant	57.1	0.9, 62.9	<0.001	56.0	54.3, 57.7	<0.001

Note. [a]Standard error calculated using Taylor Series Linearisation Method to account for complex survey design; [b]Regression only performed on domain on TV/Screen sedentary time as the model coefficients are identical for Other leisure sedentary time (reciprocal domains). CI=confidence interval.

20. Evidence to trace the impact of Study 3

The table below details how I have traced the impact of Study 3 as described in Figure 13.

Evidence description	Dates	Individuals involved and/or links to evidence where appropriate
Results of Study 3 were discussed with policy-makers at the same time as the results of Study 2. This informed the proposal to include an indicator of sedentary time on the Active Scotland Outcomes Framework.	Jan 2017	See Appendix 18.
Press coverage	Jun 2017	Coverage in print editions of The Times, The Daily Telegraph, The Independent, The Daily Mail, i, The Sun, and others. Clippings available on request. Radio interviews on The Kaye Adams show on BBC Radio Scotland, and BBC Radio Solent.
Presented findings to Scottish Physical Activity Research Collaboration conference and invited seminar at Glasgow Caledonian University.	Oct 2016	Presentations available on request. Booklet on developing interventions due for publication early 2018.
See Appendix 12 for details on work with National Health Service Health Scotland regarding obesity work. The contact began after Study 1 was published, but through discussions, the issue of sedentary behaviour was raised. In personal communication a year later, they informed us that this had influenced the way they supported the Scottish Government on obesity strategies.	Aug 2016	Deborah Shipton, Public Health Advisor (Evaluation) National Health Service Health Scotland, personal communication. Evidence summary included after this table. Meeting notes and BMedSci dissertation available on request.

21. Final report of Seedcorn-funded project

Developing a study protocol to establish the validity and reliability of the Scottish Health Survey physical activity questions: application of the 'Edinburgh Framework'

Principal applicant: Graham Baker; **Project team:** Paul Kelly, Tessa Strain,
All applicants affiliated with Sport, Physical Education and Health Sciences research cluster

Background and aims: The 'Edinburgh Framework' (EF) is a novel approach to appraise the validity and reliability of physical activity (PA) and sedentary behaviour (SB) measurement (Kelly et al, 2016). It encourages researchers to consider all aspects of validity and reliability, and ensure evidence is appropriate for the purpose of the measurement. The Scottish Health Survey (SHeS) is the national surveillance method for determining the proportion of adults that meet the aerobic PA guidelines in Scotland. However, its validity and reliability properties have not previously been appraised.

We requested Seedcorn funding to undertake the first practical application of the EF to examine the validity and reliability of the PA questions currently included in the SHeS and develop a study protocol for future research.

Methods: Evidence relating to the validity and reliability of the 2012-2015 adult SHeS PA questionnaire was identified through a directed but non-systematic "snowballing" search strategy. This included annual reports, survey documentation, Scottish Government publications, and academic articles. The theoretical framework outlined in Kelly et al. (2016) was used to guide data collection. Identified evidence was categorised under the relevant validity or reliability sub-type (e.g. convergent validity, test-retest reliability). Each sub-type was rated as good, unclear, unsupportive, or insufficient. These formed a summary rating.

Results: The validity and reliability evidence for the SHeS's ability to determine aerobic PA guideline prevalence was unclear. We rated evidence for external validity as good, convergent validity as unclear, internal reliability and face validity as unsupportive, and all other sub-types as insufficient. The issues raised by the unsupportive evidence concerned high volumes of moderate-and-vigorous PA reported and occupational PA measurement. A protocol was developed from the methods to guide future studies using the EF.

Discussion: This project has demonstrated that the evidence to support the validity and reliability of the SHeS 2012-15 PA and SB questionnaire is either insufficient or unclear. We have found that the EF was a useful practical tool to guide this process but that further development of the framework, and how to best use it, is needed.

Dissemination: An abstract based on this project has been accepted for an oral presentation at the 7th Health Enhancing Physical Activity international conference in September 2016. The results of this current work will inform our recommendations in the forthcoming consultation on the SHeS questionnaire (expected late 2016). They will also form the basis for a thesis chapter for the named research assistant (Strain) who is currently utilising the SHeS PA questions within her PhD studies.

On-going work: In our original Seedcorn application we specified a targeted funder of the Chief Scientist Office for a future funding application. However, the release of their research strategy (October 2015) suggests a different deployment of funding which would not match our proposed work (subsequent telephone communication with a CSO senior research manager confirmed this). Therefore, we are currently seeking alternative funding streams in two distinct areas. First, project team member Kelly submitted a Chancellor's Fellowship application based around further application of the EF. In our recommendations to the SHeS questionnaire consultation we will make a case for funding to be committed to this area by the Scottish Government. Second, we will seek external funding opportunities to develop and refine the EF in a Delphi style consensus exercise.

22. Differences between the Scottish Health Survey and the Health Surveys for England

Survey content	2012-15 Scottish Health Survey[a]	2008-11 Scottish Health Survey[b]	2003 Scottish Health Survey[c]	2012 Health Survey for England[d]	2008 Health Survey for England[e]	2006 Health Survey for England[f]
Occupational moderate-to-vigorous physical activity	Single-item			6 questions		Single-item
Minimum physical activity bout length (minutes)	10	10	15	10	10	15
Number of sports prompted	40	10	10	10	10	10
Older adult pace question	✓	X	X	X	X	X
Clarification question on swimming/gym activity	X	X	X	✓	✓	X
Television/ Screen time	✓	✓	✓	✓	✓	✓
Other leisure screen time	✓	X	X	X	✓	X
Sitting time at work	✓	X	X	✓	✓	X
Measures of muscle strengthening activities	✓	X	X	✓	X	X
Measures of balance and co-ordination activities	✓	X	X	X	X	X

Note. Information from [a]Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government; [b]Corbett, J., et al. (2009). The Scottish Health Survey 2008. Volume 2: Technical Report. Edinburgh: The Scottish Government; [c]Bromley, C., et al. (2004). The Scottish Health Survey 2003. Volume 4: Technical report. Edinburgh: The Scottish Government; [d]Craig, R., & Mindell, J. (2013). Health Survey for England 2012: Volume 2 Methods and documentation. Leeds: The Health and Social Care Information Centre; [e]Craig, R., et al., (2009). Health Survey for England 2008: Volume 2 Methods and documentation. Leeds: The Health and Social Care Information Centre; [f]Craig, R., & Mindell, J. (2007). Health Survey for England 2008: Volume 3 Appendix A. Leeds: The Health and Social Care Information Centre.

23. Evidence to trace impact of Study 4

The table below details how I have traced the impact of Study 4 as described in Figure 17.

Evidence description	Dates	Individuals involved and/or links to evidence where appropriate
Invited as expert to consult on potential changes to the Scottish Health Survey questionnaire in 2018 discussed in meeting (not included due to proximity to submission date).	Nov 2017	
Physical Activity for Health Research Centre response to Scottsh Health Survey questionnaire consultation on the physical activity module. Our main response was to highlight the concerns with occupational moderate-to-vigorous physical activity measurement. I created a table of alternatives to the current method.	Oct 2016	Response from PAHRC: https://consult.gov.scot/population-health/scottish-health-survey/consultation/view_respondent?uuId=794214327 Overall summary to consultation (where our concerns with occupational MVPA are highlighted): https://consult.gov.scot/population-health/scottish-health-survey/results/shs-analysisreport.pdf Alternative measurement methods of occupational MVPA included after this table.
Shared work relating to the measurement of muscle strengthening and balance and co-ordination activities with Professor Charlie Foster (who is chairing the update of the U.K. PA guidelines) and the rest of the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance.	Nov 2016 – Jul 2017	The published article for Study 2 is included in Section 7.5. Supplementary work on alternative national measurement instruments is included in Appendix 14. Personal communication with Professor Charlie Foster has indicated these were instrumental in the direction of the work of the U.K. CMOs' Expert Group for Muscle and Bone Strengthening and Balance (available on request).
Presented Study 3 findings at a seminar at Glasgow Caledonian University. This established connections between myself at Drs Philippa Dall and Sebastien Chastin. I was able to put them in touch with the relevant survey contractors and managers and ensured agreement on my proposal to change the reporting of sedentary time. The proposal has been shared with the survey manager at the Scottish Government.	Mar 2017 - ongoing	Presentation available on request. Proposed alternative questions and cognitive testing results available on request (Glasgow Caledonian Univeristy and ScotCen authored these documents). Proposal to change the reporting of ST included after this table.

Table of suggested alternatives for measurement of occupational activity referred to in consultation response.

	Advantages	**Disadvantages**
Health Survey for England questions on occupational activity (taken originally from the European Prospective Investigation into Cancer and Nutrition study) http://doc.ukdataservice.ac.uk/doc/6397/mrdoc/pdf/6397interviewingdocs.pdf	Rough analyses suggest it might not influence overall prevalence (uncertain effect on subgroups). Can use Health Survey for England data to do further checks before implementation. Would make the Health Survey for England and Scottish Health Survey questionnaires almost identical – useful for comparisons e.g. country cards. Reduces total weekly minutes of activity reported/allocated to those that are active at work.	Extra questions: 2 core questions with potential 8 additional follow-up questions (4x hours + mins) Aligning with the Health Survey for England may not be worth prioritising as future status of physical activity questionnaire uncertain. Users of the Health Survey for England questionnaire believe the measure may be a slight improvement but it is not perfect.
International physical activity questionnaire long version questions on occupational activity http://www.sdp.univ.fvg.it/sites/default/files/IPAQ_English_self-admin_long.pdf	The overall questionnaire considered to have reasonable validity and reliability. Only 2 extra questions necessary Likely to reduce total weekly minutes of occupational activity allocated/reported. Could obtain data to see expected responses at a population in advance of making changes.	Using only 2 questions from the validated questionnaire. Different style of asking about physical activity to rest of questionnaire – asking respondent to understand terms moderate-to-vigorous activity. Formatted for paper self-complete rather than interviewer led computer assisted interview.
National Health and Nutrition Examination Survey questions on occupational activity (survey in United States) http://www.cdc.gov/nchs/data/nhanes/nhanes_15_16/PAQ_I.pdf	The overall questionnaire considered to have reasonable validity and reliability. It is designed for a computer assisted interview. Likely to reduce total weekly minutes of occupational activity allocated/reported. Potential to obtain data in advance to see expected responses at a population level in advance of making changes.	Using only 6 questions from the validated questionnaire. Would have to modify to exclude housework/chores. 6 extra questions are needed – although some minor modification may be possible/necessary. Different style of asking about physical activity to rest of questionnaire – asking respondent to understand terms moderate-to-vigorous activity.

Proposal to change the reporting of sedentary time from the Scottish Health Survey

- Since 2012, the Scottish Health Survey (SHeS) has collected data on the sedentary time of adults (≥16 years) in three categories:
  1. Sitting time at work (typical work day)
  2. TV and other screen time (week day and weekend day)
  3. Any other sitting behaviours undertaken in leisure time (week day and weekend day)

- The Annual Reports have only reported on the sum of (2) and (3) i.e. total leisure sitting time.
- Middle-aged adults reported the lowest levels of leisure sitting time, older adults the most.
- The exclusion of sitting time at work may be because the assessment period differs (work day versus week or weekend day)
- However, we propose that as the majority of adults still work Monday to Friday[5], combining sitting time at work in the measure of week day sitting time is appropriate.
- We have recently published a paper doing so, and have shown that middle-aged adults report sitting for as long each week day as older adults[6].

[Questions were supplied with this document but to prevent repetition please see Appendix 6.]

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[5] European Foundation for the Improvement of Living and Working Conditions (2012). Changes over time – First findings from the fifth European working conditions survey. Dublin, Ireland: European Foundation for the Improvement of Living and Working Conditions.
[6] Tessa Strain , Paul Kelly , Nanette Mutrie & Claire Fitzsimons (2017) Differences by age and sex in the sedentary time of adults in Scotland, Journal of Sports Sciences, DOI: 10.1080/02640414.2017.1339904

24. Confidential data release form

Note that Study 5's research question was modified slightly from that described in the form; no amendment was necessary.

Confidential Data Release Form

for users of NHS personal data

NHS National Services Scotland

1 User Details
Name: **Tessa Strain**
Job title: **PhD Student**
Organisation: **University of Edinburgh**
Address:
Physical Activity for Health Research Centre
Institute for Sport, Physical Education and Health Sciences,
St Leonard's Land 2.23
The University of Edinburgh
Holyrood Road
Edinburgh EH8 8AQ
Tel No: **07799 165 501**
Data Protection Reg No: **Z6426984**
(https://ico.org.uk/ESDWebPages/DoSearch?reg=63459)

2 Sponsor Details
See Rule 6 for appropriate sponsor
Name: **Dr Claire Fitzsimons**
Job title: **Chancellor's Fellow, PhD supervisor to Tessa Strain**
Organisation: **University of Edinburgh**
Address:
Physical Activity for Health Research Centre
Institute for Sport, Physical Education and Health Sciences,
St Leonard's Land 2.23
The University of Edinburgh
Holyrood Road
Edinburgh EH8 8AQ
Tel No: **0131 651 6049**

3 Name(s) of all co-user(s):
Only the user and people listed here will have access to the data. This should include only those for whom access is essential to the work. Please see rule 3

Tessa Strain (PhD student)
Dr Claire Fitzsimons (supervisor)
Dr Paul Kelly (supervisor)

4 Nature of data requested, including a list of variables required:
Only data essential to the proposed work should be requested.

I would like to request
1. The 2012 Scottish Health Survey linked to the minimum dataset
2. The 2013 Scottish Health Survey linked to the minimum dataset
3. The 2014 Scottish Health Survey linked to the minimum dataset
4. The 2015 Scottish Health Survey linked to the minimum dataset (if available)

I would like to receive the most up-to-date datasets on
a) 10th January 2017
b) 31st July 2017

5 All purposes for which data will be used, including publications:
No data which carries the risk of identification of an individual will be put into the public domain. Please refer to the Information Services Division's (ISD) Statistical Disclosure Control Protocol and/or discuss with the ISD Head of Statistics where disclosure is a concern. Please see Rule 5

The data will be used to assess the associations between physical activity/sedentary behaviour and mortality/morbidity.

We will perform survival analyses to assess whether different levels of sedentary behaviour affect mortality (all cause, CVD, cancer) and morbidity (CVD event, hospital admission). We will adjust for physical activity levels. We hypothesise that lower levels of sedentary behaviour will be associated with lower mortality and morbidity, but we are interested to see if there is a dose-response curve.

This work forms part of a PhD thesis of which the overall aim is to use Scottish Health Survey data to inform physical activity/sedentary behaviour policy and practice in Scotland. The intention is to publish the findings in academic journals and present the results at academic conferences. The findings will also be shared with the Scottish Government. <u>All results reported will be at a population level. There will be no way of identifying an individual from the research outputs.</u>

The reason for requesting the datasets on two occasions is to maximise the follow up period of health data but still meet my PhD submission deadline. I have been advised that the best method to do this is to request the data when I initially require it (10th Jan 2017) which will allow me to set up the analyses that I plan to run. I hope that by the 31st July 2017, another year of health data will have been added to the dataset and I will be able to use this in my final analyses.

Should the project yield promising results, we may request a further update of the minimum dataset in the future (5+ years' time) to re-run the analyses with an even greater follow up period.

6 Proposed method of transfer of data:
The final decision will be taken in consultation with the NSS analyst and should comply with NSS policy

I expect to receive the data via SSH File Transfer Protocol but will adapt to whatever the preferred method is.

7 Measures in place to protect and use the data securely and confidentially:
Describe the physical and electronic systems for data storage and access

The data will be stored in an encrypted folder in DataStore (the University of Edinburgh's secure storage space). DataStore has a fully redundant / resilient infrastructure, with daily snapshots every weekday morning and daily backups to off-site tape every evening, and a disaster recovery to second site over nights. It is professionally managed by the IT Infrastructure Team with Access Control Lists via ED Active Directory (File-store Allocation Policy: http://www.ed.ac.uk/files/imports/fileManager/rdm-filestore-final.pdf)

Only the named researchers (Strain, Fitzsimons, Kelly) will have access to the encrypted folder. In order to access the folder, each user will need to be logged into their own personal University of Edinburgh account. They will then need a further password (shared between the research team) to access the data folder.

8 Intended duration of use of data:
All users and co-users must agree to destroy the data after an agreed date using a certificated electronic destruction process. Paper data must also be destroyed

Once the analyses have been completed (latest date 31st July 2018), the data will be stored in DataVault (the University of Edinburgh's secure archive that will be launched in 2016).

In line with guidance from the University, the data will be stored here for 10 years after the completion of analyses. Therefore the anticipated date of secure destruction of the data will be 31st July 2028.

Should the researchers move on from the University of Edinburgh, Tessa Strain will take responsibility to make sure that the data are destroyed at the required date.

9 Date data to be destroyed:
Staff from NSS may contact to confirm destruction

31st July 2028

User's Declaration
I declare that I understand and undertake to abide by the Rules for confidentiality, security and release of data received from NSS as specified in paragraphs 1-5 listed below.

Signature: T Strain Date: 14th April 2016

Sponsor's Declaration
I declare that **Tessa Strain** (name above as the user of the data requested), is a bona fide worker engaged in a reputable project and that the data requested can be entrusted to him/her in the knowledge that (s)he will conscientiously discharge his/her obligations in regard to confidentiality of the data, as stated in paragraphs 1-5 listed below. I am happy for him/her to receive these data.

Signature: Claire Fitzg Date: 14 April 2016

Professional registration no.: eg GMC/GDC ____________N/A_____________

For NSS only
Caldicott Guardian, NHS National Services Scotland, Gyle Square, 1 South Gyle Crescent, Edinburgh, EH12 9EB

Information request number ____

Release authorised by

________________________________Date____________ Senior manager (HOG or HOP)

________________________________Date____________ Caldicott Guardian or deputy

RULES ON CONFIDENTIALITY, SECURITY AND RELEASE OF INFORMATION FOR USERS OF NHS PERSONAL DATA

1. Personal data held by NSS have been notified under the Data Protection Act 1998 for the purposes of:

Staff Administration	Licensing and Registration
Advertising, Marketing and Public Relations	Research
Accounts and Records	Crime Prevention and Prosecution of Offenders
Consultancy and Advisory Services	Administration of Justice
Health Administration and Services	Trading/sharing in Personal Information
Information and Databank Administration	Blood Transfusion (Blood, Tissue and Stem Cells) Services
Legal Services	Lending and Hire Services, Library Services
Public and Environmental Health Surveillance and Analysis	Transfer of Primary Medical Records by Practitioner Services
Education	National Fraud Initiative – Data Matching

It cannot be used for any other purposes.

2. If the data received from NSS are to be held on computer, the signatory of this request, or the organisation they represent, should have an appropriate notification with the Office of the Information Commissioner. Details of the registration number should be entered on page 1 of this document. Whether stored on computer or otherwise, the signatory should be aware that the Data Protection Act 1998 requires that all personal data is processed fairly and lawfully and in accordance with the Data Protection Principals.

3. Data received from NSS should not be divulged to any person whose name is not specified as a 'co-user of data' nor used for any purpose other than that declared on page 1 (Intended use of data) of this document. All users and co-users must understand their responsibilities in protecting data provided.

4. Proper safeguards should be applied in keeping the data secure and destroying it on completion of the work/project declared on page 1 to prevent any breach of confidentiality. Any misuse or loss of these data should be notified immediately to the NSS Data Protection Officer **nss.dataprotection@nhs.net**

5. Statistics or results of research based on data received from NSS should not be made available in a form which:
   a) directly identifies individual data subjects or creates a risk of indirect identification. The risk should be assessed using ISD's Statistical Disclosure Control Protocol and may be discussed with the ISD Head of Statistics if disclosure is a concern;
   b) is not covered by the 'intended use of data' clause specified on page 1.

6. Sponsor Details on form:
   - For release to NHS operational units of data relating to their own treated patients the sponsor should be the unit's Medical Director. For releases of data relating to patients in a specific directorate, the relevant Clinical Director may sign the statement.
   - For release to NHS Boards of data relating to their resident population the sponsor should be Director of Public Health.
   - For release to CHPs of data relating to their resident population or of people treated in their units, the sponsor should be the Clinical Director of the CHP
   - For release of data to General Practice regarding their registered patients, the sponsor should be a GP principal in that practice.
   - For releases to researchers of data which have not required PAC authorisation, the sponsor will be the registered health professional responsible for ensuring the confidentiality of the data.
   - For release of data to an organisation holding a contract with an NHS Board or with the Scottish Government: for the purpose of fulfilling that contract the sponsor will be the NHS Board Director of Public Health or a registered health professional in the Scottish Government.
   - For release of workforce data, the sponsor should be a senior manager in the organisation to which data will be released

7. The information provided to you is derived from systems used in the NHS for the administration of health services or from the registrations held by the General Register Office for Scotland. Although there are quality assurance processes in place, the data may contain undetected inaccuracies about an individual patient, member of staff or department. Therefore the data are not collected for the purpose of informing direct clinical decisions about individual patients, or judging the performance of individual staff and should be verified if to be used for either of these purposes.

8. A signed paper copy of the confidentiality statement should be sent to the analyst by mail or by fax to the following fax no. 0131 275 7606

NSS would welcome copies of any publications based on data supplied.

25. Timeline

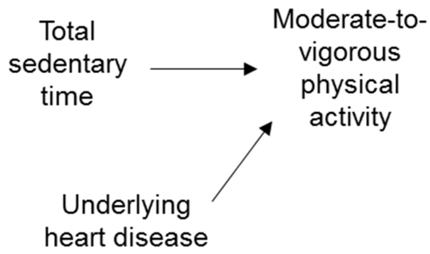
	2016				2017											2022				2023			
	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec
Preliminary analyses (included in present thesis)																							
Broad research question confirmed																							
Broad study design confirmed																							
Dataset access sought																							
Internal ethics form submitted																							
Background literature reading																							
Transfer of preliminary datasets																							
Preparing the datasets (merging, deriving variables)																							
Writing the analysis code																							
Intended transfer of update to preliminary datasets																							
Processing preliminary results																							
Writing Study 5 chapter for thesis																							
Securing archiving/disposing of data																							
Final analyses																							
Potential grant application for funding																(or earlier)							
Reseeking dataset access																							
Submit internal ethics form																							
Data expected to be available																							
Transfer of datasets																							
Prepare the datasets (use previously developed code for merging and deriving variables)																							
Run the analysis code																							
Interpret results																							
Write up research paper (possible separate paper for results of sensitivity analyses)																							
Submit for publication																							
Knowledge exchange activities e.g. with Scottish Government, at academic conferences																							

26. Example of collider bias

The following example is heavily based on one explained by Cole et al. (2010) but adapted to a MVPA/ST context.

Step 1.

Assume that the diagram to the right represents the true relationships between ST, MVPA, and underlying heart disease. The assumptions are as follows: (1) high ST levels cause low MVPA levels, (2) underlying heart disease causes low MVPA levels, and (3) there is no relationship between underlying heart disease and ST levels.



Step 2.

The table below summarises data from a sample of 100 adults taken from a population where the relationships described above are true.

	Heart disease		Total (n)	Relative risk of heart disease	Risk difference
	Heart disease (n)	No heart disease (n)			
High sedentary time	5	45	50	0.1	0.0
Low sedentary time	5	45	50	0.1	

Step 3.

The following table shows how the data may look if stratified by MVPA level (55 individuals had low MVPA). It shows how adjusting for MVPA induces a spurious relationship between ST and underlying heart disease (collider bias). This is relevant to Study 5 because a factor such as underlying heart disease could be related to the longer term NCD outcomes.

	Underlying heart disease		Total (n)	Relative risk	Risk difference
	Heart disease (n)	No heart disease (n)			
Low MVPA					
High sedentary time	5	45	50	0.1	0.9
Low sedentary time	5	0	5	1.0	
High MVPA					
High sedentary time	0	0	0	N/A	N/A
Low sedentary time	0	45	45	0.0	

27. Research ethics recommendations to Moray House School of Education

A document of recommendations submitted in August 2017

The issues

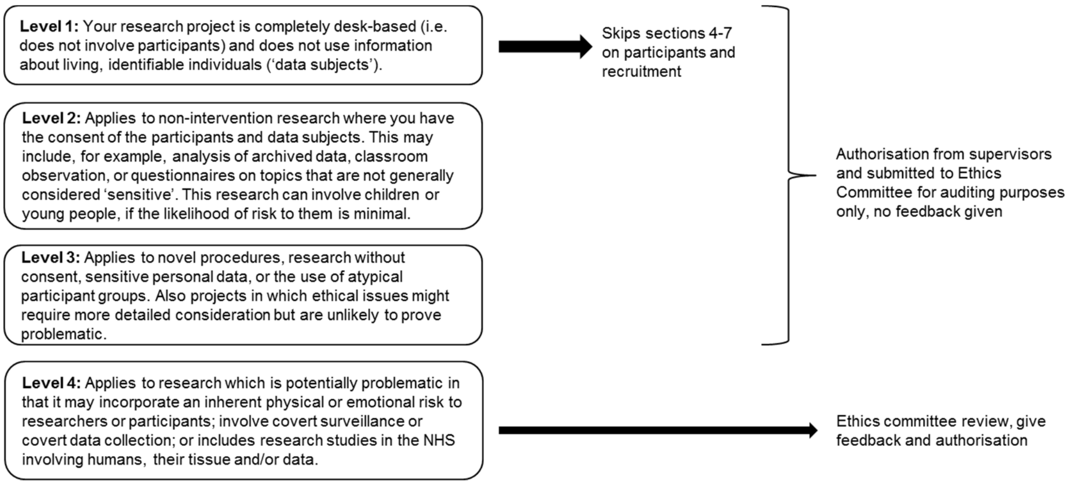
There are three key issues around applying for ethical approval for secondary analysis projects in the current Moray House School of Education (MHSE) system:

i) it is not clear what level projects that work with identifiable or sensitive data are
ii) the Level 1 application form does not allow for sufficient interrogation of the ethical issues of secondary data analysis
iii) it is unclear how the application form links with any other agreements made to access the data.

This document will briefly describe the current system and suggest two recommendations for change that would solve these issues.

The current system

The current MHSE ethical approval system can be summarised by the figure below:



Recommendation 1: change description of the levels to cover secondary analysis situations

I suggest adding text to the Level 1, 2, and 4 descriptions such that it is clear where secondary analysis projects would fit. The changes (see below in red) would encourage students to consider the level of risk associated with the data they are using, and whether there are already arrangements in place to mitigate them.

Suggested changes to the descriptions of levels of ethical approval

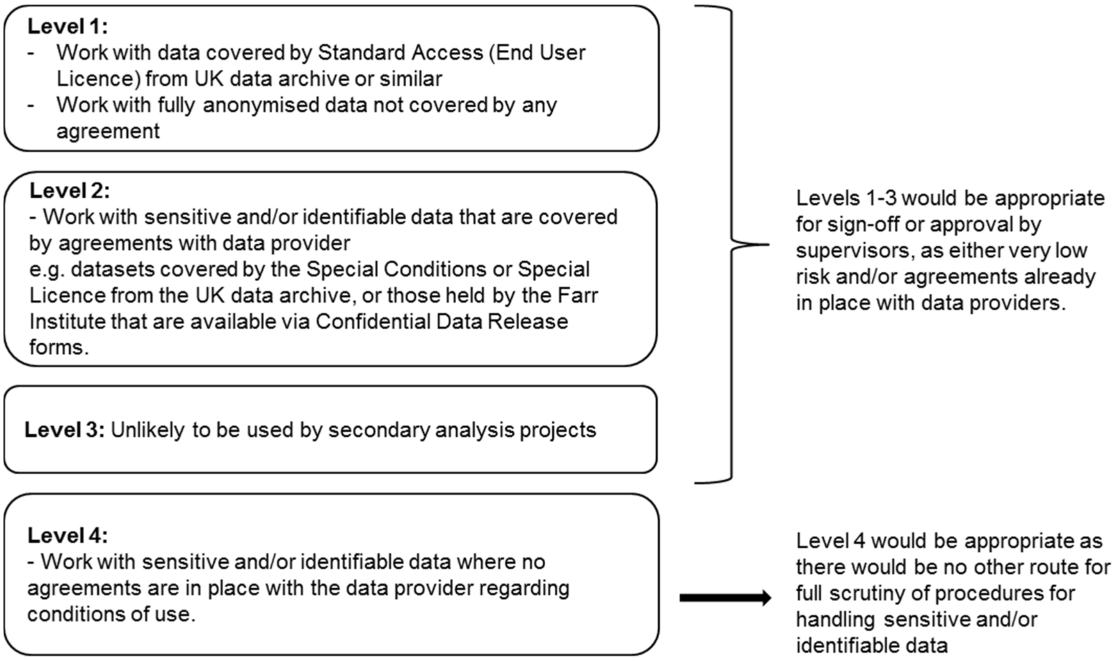
Level 1: Your research project is completely desk-based (i.e. does not involve direct contact with participants). Any data relating to ~~and does not use information about living, identifiable~~ individuals ('data subjects') are fully anonymised. Also applies to projects seeking sign-off that already have agreements with data providers to access such anonymised data.

Level 2: Applies to non-intervention research where you have the consent of the participants and data subjects. This may include, for example, analysis of archived data, classroom observation, or questionnaires on topics that are not generally considered 'sensitive'. This research can involve children or young people, if the likelihood of risk to them is minimal. Also applies to secondary data analysis projects seeking sign-off that already have agreements with the data provider to access identifiable or sensitive data.

Level 3: Applies to novel procedures, research without consent, sensitive personal data, or the use of atypical participant groups. Also projects in which ethical issues might require more detailed consideration but are unlikely to prove problematic.

Level 4: Applies to research which is potentially problematic in that it may incorporate an inherent physical or emotional risk to researchers or participants; involve covert surveillance or covert data collection; or includes research studies in the NHS involving humans, their tissue and/or data. Also applies to secondary data analysis of identifiable and/or sensitive information where no agreements over access and use have been made with the data provider.

The figure below shows examples for each level and how this would provide an appropriate level of review:



There is a nuanced difference between "sign-off" and "approval" for some Level 1 and 2 projects. If agreements are already in place with the data providers, then it would be inappropriate for further ethical approval to be sought. In this case, the student should seek "sign-off" from their supervisor. This is a necessary step and is provides an audit trail for both the student and MHSE.

Recommendation 2: Identify projects as secondary analysis regardless of Level, allowing them to skip sections 4-7 and to answer more relevant questions in section 8.

I recommend that the application form is modified so that that a project is identified as secondary analysis after the level is selected. If flagged as secondary analysis, the ethics form will avoid sections 4-7 on participant information. It would also then route them to an alternative version of Section 8.

I suggest the alternative section 8 includes the following questions:

8.1 **Description of dataset** (include details on topics, whether sensitive or not, anonymisation levels). Consider whether individuals may be identified by their answers, even if the data is anonymised.

8.2 **Purposes of use of the dataset** (include all intended uses of the data, e.g. publication, poster). Confirm that no individual will be able to be identified from the research outputs. Explain how the consent given by the participants covers the proposed uses.

8.3 **Data transfer and storage** Describe the method through which the data will be transferred and how the data will be stored in an appropriate manner. Describe who will have access to the data.

8.4 **Duration of use and destruction of data** For how long will the data be used, when and how will it be destroyed. Who is responsible for this happening.

(Existing questions 8.8 and 8.9 may need to remain in this alternative version).

If agreements are already in place with the data provider, then these should be detailed in the existing question 2.3. Section 8 should still be filled out.

28. MET values assigned to activities in Study 5

This table details the intensity level I assigned to sport and exercise activities in Study 5

Sport	Follow-up question response	SHeS assigned intensity level[a]	Compendium listed activity[b]	Compendium MET value assigned[b]
Fishing/angling	No	L	Not needed	N/A
Snooker/billiards/ pool	N/A	L	Not needed	N/A
Yoga/pilates	No	L	Not needed	N/A
Tenpin bowling	N/A	L	Not needed	N/A
Walking/jogging on treadmill	No	L	Not needed	N/A
Aerobics/keep fit/gym/dance for fitness	No	M	Aerobic low impact	5
Badminton/Tennis	No	M	Tennis hitting balls, non-game play	5
Cycling	No	M	Bicycling to work or for pleasure	4
Dancing (any other)	No	M	Ballroom, slow (e.g. waltz, foxtrot, slow dancing, samba, tango, 19th century dance, mambo, cha cha)	3
Exercises	No	M	Home exercise, general, and calisthenics (e.g. push ups, sit ups, pull-ups, lunges) moderate effort	3.8
Running/jogging	No	M	Running (15 min/mile)	6
Swimming	No	M	Swimming laps, slow, light, or moderate effort	5.8
Workout at gym/Exercise bike/Weights	No	M	Health club exercise classes, general, gym/weight training combined in one visit	5
Bowls	N/A	M	Lawn bowls	3.3
Fishing/angling	Yes	M	Fishing, general	3.5

Golf	N/A	M	Golf, general	4.8
Hill walking/ Rambling	No	M	Hiking or walking at a normal pace through fields and hillsides	5.3
Aquarobics	No	M	Water aerobics, water calisthenics	5.5
Yoga/pilates	Yes	M	Yoga, power	4
Athletics	No	M	Track and field (e.g. high jump, long jump, triple jump, javelin, pole vault)	6
Basketball	No	M	Basketball, shooting baskets	4.5
Canoeing/ Kayaking	No	M	Canoeing, rowing, for pleasure	3.5
Climbing	No	M	Rock climbing, low to moderate difficulty	5.8
Cricket	N/A	M	Cricket, batting, bowling, fielding	4.8
Curling	N/A	M	Curling	4
Horse Riding	No	M	Horse riding, walking	3.8
Ice skating	No	M	Skating, ice, 9mph or less	5.5
Martial Arts incl. Tai Chi	No	M	Martial arts different types slower pace	5.3
Netball	No	M	Basketball, shooting baskets [No netball value given]	4.5
Powerboating/ Jet Skiing	No	M	No moderate intensity activity listed on compendium	4.5
Rowing	No	M	Canoeing, rowing, for pleasure	3.5
Sailing/ Windsurfing	No	M	Sailing general	3
Skateboarding/ Inline skating	No	M	Skateboarding general, moderate effort	5
Skiing/ Snowboarding	No	M	Skiing downhill light effort	4.3
Surf/Body boarding	N/A	M	Surfing body or board, general	3
Table tennis	N/A	M	Table tennis, ping pong	4

Volleyball	No	M	Volleyball non-competitive 6-9 member team, general	3
Water Skiing	N/A	M	Skiing, water or wakeboarding	6
Abseiling/ Parasailing	N/A	M	No moderate intensity activity listed on compendium	4.5
Archery	N/A	M	Archery, non-hunting	4.3
Assault Course	N/A	M	No moderate intensity activity listed on compendium	4.5
Baseball/Softball	N/A	M	Softball or baseball, fast or slow pitch, general	5
Boxing	No	M	No moderate intensity activity listed on compendium	4.5
Circuit Training	No	M	Circuit training, moderate effort	4.3
Croquet	N/A	M	Croquet	3.3
Diving	N/A	M	Diving, springboard or platform	3
Dog training	N/A	M	No moderate intensity activity listed on compendium	4.5
Drumming (in a group)	N/A	M	No moderate intensity activity listed on compendium	4.5
Field athletics	No	M	Track and field (e.g. shot, discus, hammer throw)	4
Hang gliding	N/A	M	Hang gliding	3.5
Hiking	No	M	Hiking or walking at a normal pace through fields and hillsides	5.3
Motor sports	N/A	M	moto-cross, off road motor sports, all-terrain vehicle, general	4
Rounders	N/A	M	No moderate intensity activity listed on compendium	4.5
Skirmishing (war games)	N/A	M	No moderate intensity activity listed on compendium	4.5
Snorkelling	N/A	M	Snorkelling	5
Swing ball	N/A	M	No moderate intensity activity listed on compendium	4.5
Trampolining	N/A	M	Trampoline recreational	3.5
Walking/jogging on treadmill	Yes	M	Walking 4 mph level firm surface very brisk pace	5

Other moderate	N/A	M		4.5
Aerobics/keep fit/gym/dance for fitness	Yes	V	Aerobic, high impact	7.3
Badminton/Tennis	Yes	V	Tennis general	7.3
Cycling	Yes	V	Fast, vigorous effort	10
Dancing (any other)	Yes	V	General dancing (e.g. disco, folk, Irish step dancing, line dancing, polka, contra, country)	7.8
Exercises	Yes	V	Calisthenics (e.g. push ups, sit ups, pull-ups, lunges) vigorous effort	8
Football/rugby	N/A	V	Soccer competitive	10
Running/jogging	Yes	V	Running (7 min/mile)	12.3
Squash	N/A	V	Squash general	7.3
Swimming	Yes	V	Swimming laps, fast, vigorous effort	9.8
Workout at gym/Exercise bike/Weights	Yes	V	Health club conditioning classes	7.8
Hill walking/ Rambling	Yes	V	Climbing hills with 42+ lb load	9
Aquarobics	Yes	V	No vigorous intensity activity listed on compendium	7
Athletics	Yes	V	Track and field (e.g. steeple chase, hurdles)	10
Basketball	Yes	V	Basketball, game	8
Canoeing/ Kayaking	Yes	V	Canoeing, rowing, kayaking, vigorous effort	12.5
Climbing	Yes	V	Rock or mountain climbing	8
Hockey	N/A	V	Hockey, field	7.8
Horse Riding	Yes	V	Horse riding, canter or gallop	7.3
Ice skating	Yes	V	Skating, ice, general	7

Martial Arts incl. Tai Chi	Yes	V	Martial arts different types moderate pace	10.3
Netball	Yes	V	Basketball, game [No netball value given]	8
Powerboating/ Jet Skiing	Yes	V	Jet skiing, driving, in water	7
Rowing	Yes	V	Canoeing, rowing, kayaking, vigorous effort	12.5
Sailing/ Windsurfing	Yes	V	Sailing in competition [No compendium justification for the SHeS vigorous rating]	4.5
Shinty	N/A	V	Hockey, field [No shinty value given]	7.8
Skateboarding/ Inline skating	Yes	V	Skateboarding general, vigorous effort	6
Skiing/ snowboarding	Yes	V	Skiing, general	7
Subaqua	N/A	V	Skin diving, scuba diving, general	7
Volleyball	Yes	V	Volleyball competitive in gymnasium	6
Boxing	Yes	V	Boxing in ring, general	12.8
Circuit Training	Yes	V	Circuit training, including kettlebells, some aerobic movement with minimal rest, general, vigorous intensity	8
Field athletics	Yes	V	Track and field (e.g. high-, long- and triple jump, javelin, pole vault)	6
Hiking	Yes	V	Climbing hills with 42+ lb load	9
Kick boxing	N/A	V	Martial arts, different types, moderate pace - includes kick boxing	10.3
Orienteering	N/A	V	Orienteering	9
Skipping	N/A	V	Rope jumping moderate pace	11.8
Other vigorous	N/A	V		7

Note. SHeS = Scottish Health Survey; MET = Metabolic Equivalents of Task. Information from [a]Campbell-Jack, D., & Hinchliffe, S. (2016). The Scottish Health Survey 2015. Volume 2: Technical Report. Edinburgh: The Scottish Government; [b]Ainsworth, B. E., et al. (2011). 2011 Compendium of physical activities: A second update of codes and MET values. Medicine & Science in Sports & Exercise, 43(8), 1575-1581; When there was not an appropriate activity or value listed on the compendium, I used a similar sport (e.g. basketball/netball). If none were available, I assigned 4.5 METs to those considered moderate and 7 METs to those considered vigorous.

Activity	Compendium listed activity[a]	MET value assigned[a]
Self-reported walking pace		
For 18-64 year olds		
Brisk	Walking, 3.5mph, level, brisk, firm surface, walking for exercise	4.3
Fast	Walking, 4.0mph, level, firm surface, very brisk pace	5
For those over 65 years		
Slow	Walking, less than 2.0 mph, level, strolling, very slow	2
Steady average	Walking from house to car or bus, from car or bus to go places, walking to neighbours house or family house for social reasons	2.5
Brisk	Walking, 2.5mph level firm surface	3
Fast	Walking, 3.5mph, level, brisk, firm surface, walking for exercise	4.3
Heavy housework		
Moving heavy furniture	Moving furniture, household items, carrying boxes	5.8
Spring cleaning	Cleaning, sweeping carpet or floors, general	3.3
Walking with heavy shopping (for more than 5 minutes)	Putting away groceries (e.g. carrying groceries, shopping without a grocery cart), carrying packages	2.3
Cleaning windows	Cleaning windows	3.2
Scrubbing floors with a scrubbing brush	Scrubbing floors on hands and knees, scrubbing bathroom, bathtub, light effort	2
	Median value	3.2
Heavy manual, do-it-yourself maintenance, gardening		
Digging, clearing rough ground	Digging, spading, filling garden, composting, light-to-moderate effort	3.5
Building in stone/bricklaying	Laying crushed rock	6.3
Mowing large areas with a hand mower	Mowing lawn, walk, hand mower	6
Felling trees, chopping wood	Chopping wood, splitting logs, moderate effort	4.5
Mixing/laying concrete	Masonry, concrete, light effort	2.3
Moving heavy loads	Carrying, loading or stacking wood, loading/unloading or carrying lumber, light to moderate effort	3.3
Refitting a kitchen or bathroom	Plumbing activities	3
	Median Value	3.5

Note. MET: Metabolic Equivalents of Task. Information from [a]Ainsworth, B. E., et al. (2011). 2011 Compendium of physical activities: A second update of codes and MET values. Medicine & Science in Sports & Exercise, 43(8), 1575-1581.

29. Selection of covariates

The following table shows the process of selecting covariates described in Section 11.2.4.

	Potential correlate	Identified as correlate by Bauman[a]	Identified as correlate by O'Donoghue[b]	Identified as predictor by Leadbetter[c]	Variable in Scottish Health Survey	Reference for evidence of association with all-cause mortality	Reference for evidence of association with cardiovascular disease incidence and/or mortality	Reference for evidence of association with cancer diagnosis and/or mortality	Reference for evidence of association with diabetes incidence and/or related-event
	Demographic								
1	Age	Yes	Yes	Yes	Age	Office for National Statistics. (2016). National Life Tables, UK: 2013-2015. Newport, UK: Office for National Statistics.	Information Services Division. (2017). Scottish Heart Disease Statistics. Edinburgh, UK: Information Services Division.	Information Services Division. (2017). Cancer Incidence in Scotland. Edinburgh, UK: Information Services Division.	Scottish Diabetes Survey Monitoring Group. (2016). Scottish Diabetes Survey 2015. Edinburgh, UK: NHS Health Scotland.
2	Sex	No	Yes	Yes	Sex				
3	Education	No	Yes	No	Highest education level achieved	Hummer, R. A., & Hernandez, E. M. (2013). The effect of educational attainment on adult mortality in the United States. Population bulletin, 68(1), 1-16.	Kaplan, G. A. and J. E. Keil (1993). "Socioeconomic factors and cardiovascular disease: a review of the literature." Circulation 88(4 Pt 1): 1973-1998.	Mouw, T., Koster, A., Wright, M. E., Blank, M. M., Moore, S. C., Hollenbeck, A., & Schatzkin, A. (2008). Education and risk of cancer in a large cohort of men and momen in the United States. PLoS One, 3(11), e3639.	Sacerdote, C., Ricceri, F., Rolandsson, O., Baldi, I., Chirlaque, M. D., Feskens, E. J., ...Wareham, N. J. (2012). Lower educational level is a predictor of incident type 2 diabetes in European countries: the EPIC-InterAct study. International Journal of Epidemiology, 41(4), 1162-1173.
4	Measures of income, socioeconomic status, economic activity status	No	Yes	Yes	Equivalised Household income	Rehkopf, D. H., Berkman, L. F., Coull, B., & Krieger, N. (2008). The non-linear risk of mortality by income level in a healthy population: US National Health and Nutrition Examination Survey mortality follow-up cohort, 1988–2001. BMC Public Health, 8, 383-383.		Clegg, L. X., Reichman, M. E., Miller, B. A., Hankey, B. F., Singh, G. K., Lin, Y. D., . . . Edwards, B. K. (2009). Impact of socioeconomic status on cancer incidence and stage at diagnosis: selected findings from the surveillance, epidemiology, and end results: National Longitudinal Mortality Study. Cancer causes & control, 20(4), 417-435.	Rabi, D. M., Edwards, A. L., Southern, D. A., Svenson, L. W., Sargious, P. M., Norton, P., . . . Ghali, W. A. (2006). Association of socio-economic status with diabetes prevalence and utilization of diabetes care services. BMC Health Services Research, 6, 124-124.
					Scottish Index of Multiple Deprivation (based on postcode)	National Records of Scotland. (2016). Life Expectancy for Administrative Areas within Scotland 2013-2015. Edinburgh, UK: National Records of Scotland.			Read, S. H., Kerssens, J. J., McAllister, D. A., Colhoun, H. M., Fischbacher, C. M., Lindsay, R. S., . . . Wild, S. H. (2016). Trends in type 2 diabetes incidence and mortality in Scotland between 2004 and 2013. Diabetologia, 59(10), 2106-2113.
					Economic activity status	Jin, R. L., Shah, C. P., & Svoboda, T. J. (1995). The impact of unemployment on health: a review of the evidence. Canadian Medical Association Journal, 153(5), 529-540.	Weber, A., & Lehnert, G. (1997). Unemployment and cardiovascular diseases: A causal relationship? International Archives of Occupational and Environmental Health, 70(3), 153-160.	Lynge, E. (1997). Unemployment and cancer: A literature review. IARC Scientific Publications(138), 343-351.	Robinson, N., Yateman, N. A., Protopapa, L. E., & Bush, L. (1989). Unemployment and diabetes. Diabetic Medicine, 6(9), 797-803.
5	Ethnicity/Race	No	Yes		Ethnicity	Rees, P., & Wohland, P. (2008). Estimates of Ethnic Mortality in the UK. Working Paper. Leeds, UK: The University of Leeds.	Landman, J., & Cruickshank, J. K. (2001). A review of ethnicity, health and nutrition-related diseases in relation to migration in the United Kingdom. Public Health Nutrition, 4(2b), 647-657.		
6	Student (or hobby/ occupation requiring additional study)		Yes		Work status				
7	Office worker or not		Yes		Not in the SHeS				

	<u>Health status/ behaviours</u>								
8	Health status/perceived health	Yes	Yes	Yes	Self-reported general health status	Idler, E. L., & Benyamini, Y. (1997). Self-rated health and mortality: a review of twenty-seven community studies. Journal of Health and Social Behavior, 38(1), 21-37.	Mavaddat, N., Parker, R. A., Sanderson, S., Mant, J., & Kinmonth, A. L. (2014). Relationship of self-rated health with fatal and non-fatal outcomes in cardiovascular disease: a systematic review and meta-analysis. PLoS One, 9(7), e103509.	Riise, H. K., Riise, T., Natvig, G. K., & Daltveit, A. K. (2014). Poor self-rated health associated with an increased risk of subsequent development of lung cancer. Quality of Life Research, 23(1), 145-153.	Wennberg, P., Rolandsson, O., van der A, D. L., Spijkerman, A. M. W., Kaaks, R., Boeing, H., ...Wareham, N. J. (2013). Self-rated health and type 2 diabetes risk in the European Prospective Investigation into Cancer and Nutrition-InterAct study: A case-cohort study. BMJ Open, 3(3), e002436.
9	Overweight/obesity/ Body mass index				BMI	Aune, D., Sen, A., Prasad, M., Norat, T., Janszky, I., Tonstad, S., ...Vatten, L. J. (2016). BMI and all cause mortality: Systematic review and non-linear dose-response meta-analysis of 230 cohort studies with 3.74 million deaths among 30.3 million participants. BMJ, 353, i2156.	Flint, A. J., Rexrode, K. M., Hu, F. B., Glynn, R. J., Caspard, H., Manson, J. E., ...Rimm, E. B. (2010). Body mass index, waist circumference, and risk of coronary heart disease: A prospective study among men and women. Obesity Research & Clinical Practice, 4(3), e171-e181.	Bhaskaran, K., Douglas, I., Forbes, H., dos-Santos-Silva, I., Leon, D. A., & Smeeth, L. (2014). Body-mass index and risk of 22 specific cancers: A population-based cohort study of 5.24 million UK adults. The Lancet, 384(9945), 755-765.	Ganz, M. L., Wintfeld, N., Li, Q., Alas, V., Langer, J., & Hammer, M. (2014). The association of body mass index with the risk of type 2 diabetes: A case-control study nested in an electronic health records system in the United States. Diabetology & Metabolic Syndrome, 6(1), 50.
10	Previous physical activity behaviour	Yes			Not in the SHeS				
11	Food cravings		Yes		Not in the SHeS				
12	Smoking		Yes	Yes	Self-reported smoking status	Jacobs, D. R., Jr., Adachi, H., Mulder, I., Kromhout, D., Menotti, A., Nissinen, A., & Blackburn, H. (1999). Cigarette smoking and mortality risk: Rwenty-five-year follow-up of the Seven Countries Study. Archives of Internal Medicine, 159(7), 733-740.			Willi, C., Bodenmann, P., Ghali, W. A., Faris, P. D., & Cornuz, J. (2007). Active smoking and the risk of type 2 diabetes: A systematic review and meta-analysis. Journal of the American Medical Association, 298(22), 2654-2664.
13	Poor sleeping habits		Yes		Not in the SHeS				
14	Chronic disease		Yes		Outcome				
15	Limiting illness/ Disability/Injury		No	Yes	Limiting long-standing illness	Forman-Hoffman, V. L., Ault, K. L., Anderson, W. L., Weiner, J. M., Stevens, A., Campbell, V. A., & Armour, B. S. (2015). Disability status, mortality, and leading causes of death in the United States community population. Medical Care, 53(4), 346-354.			McDermott, S., Moran, R., Platt, T., & Dasari, S. (2007). Prevalence of diabetes in persons with disabilities in primary care. Journal of Developmental and Physical Disabilities, 19(3), 263-271
16	Hormone use		Yes		Sub-sample only				
17	Medication		Yes		Sub-sample only				
18	Mental wellbeing			Yes	Warwick-Edinburgh Mental Wellbeing scale	Chida, Y., & Steptoe, A. (2008). Positive psychological well-being and mortality: A quantitative review of prospective observational studies. Psychosomatic Medicine, 70(7), 741-756.	Boehm, J. K., Peterson, C., Kivimaki, M., & Kubzansky, L. D. (2011). A prospective study of positive psychological well-being and coronary heart disease. Health Psychology, 30(3), 259-267.	Feller, S., Teucher, B., Kaaks, R., Boeing, H., & Vigl, M. (2013). Life satisfaction and risk of chronic diseases in the European Prospective Investigation into Cancer and Nutrition (EPIC)-Germany study. PLoS One, 8(8), e73462.	
19	Physical activity levels		Yes		Exposure				
20	Sedentary behaviour habits		Yes		Exposure				
21	TV viewing time		Yes		Exposure				

	Environmental								
22	Recreation facilities	Yes			Not in the SHeS				
23	Transport environment	Yes			Not in the SHeS				
24	Aesthics	Yes			Not in the SHeS				
	Psychosocial, social, cultural								
25	Attitudes	No	Yes		Not in the SHeS				
26	Intention	Yes	Yes		Not in the SHeS				
27	Action planning	Yes			Not in the SHeS				
28	Self efficacy	Yes			Not in the SHeS				
29	Stage of change	Yes			Not in the SHeS				
30	Stress/Depressive symptoms/Anxiety	No	Yes		General Health Questionnaire	Russ, T. C., Stamatakis, E., Hamer, M., Starr, J. M., Kivimäki, M., & Batty, G. D. (2012). Association between psychological distress and mortality: Individual participant pooled analysis of 10 prospective cohort studies. BMJ, 345, e4933.	Musselman, D. L., Evans, D. L., & Nemeroff, C. B. (1998). The relationship of depression to cardiovascular disease - epidemiology, biology, and treatment. Archives of General Psychiatry, 55(7), 580-592.	Batty, G. D., Russ, T. C., Stamatakis, E., & Kivimaki, M. (2017). Psychological distress in relation to site specific cancer mortality: Pooling of unpublished data from 16 prospective cohort studies. BMJ, 356, j108.	Mezuk, B., Eaton, W. W., Albrecht, S., & Golden, S. H. (2008). Depression and type 2 diabetes over the lifespan: A meta-analysis. Diabetes Care, 31(12), 2383-2390.
31	Physical activity characterstics and perceived effort	Yes			Exposure				
32	Percieved benefits of reducing sedentary time		Yes		Not in the SHeS				
33	Commitment to work		Yes		Not in the SHeS				
34	Preference for sedentary behaviour		Yes		Not in the SHeS				

Note. a: identified as a correlate if at least half the number of included reviews that assessed the variable reported it as a correlate for either total physical activity, or non-occupational physical activity; b: identified as a correlate if at least half the studies that included it as a correlate reported a consistent association with total self-reported sitting time; c: significant ($p<0.05$) predictor of meeting MVPA guidelines amongst all adults in the SHeS 2012. Blank indicates the covariate was not mentioned by the review/paper. SHeS: Scottish Health Survey; BMI: body mass index. References included in this table do not feature in the main thesis reference list.

In the next step covariates were excluded due to high proportion of missing data on analysis sample: equivalised household income (40%), ethnicity (68%), body mass index (12%), Warwick-Edinburgh Mental Well-being Scale (5%), General Health Questionnaire (5%).

Three pairs of variables that showed strong correlations with each other. Each of the six variables included in the comparisons above was included in a Cox proportional hazards model with MVPA-ST category. The outcome was ACM; age was the underlying time scale. Adjusted Wald tests were performed to give an indication of the strength of the association between the covariate and the outcome. P values were used as a crude measure of this (see Table 1 below). The variable with the lowest p values was included in the fully-adjusted model (deprivation quintile and work status). In the case of self-reported general health and limiting long-standing illness, the F-statistic values could be compared because the degrees of freedom were the same. Self-reported general health was included due to the higher F-statistic value (indicating stronger association).

Table 1. The Results of the Adjusted Wald Tests

Potential covariate	Adjusted Wald test statistic	*p*
Highest education level acheived	F (2, 1202) = 0.99	.37
Deprivation quintile	**F (4, 1200) = 2.48**	**.04**
Work status	F (1, 1203) = 7.56	.01
Economic activity status	**F (3, 1201) = 4.78**	**<.01**
Self-reported general health	**F (2, 1202) = 28.69**	**<.001**
Limiting long-standing illness	F (2, 1202) = 9.30	<.001

Note. Bold indicates variables selected

30. Weighting in Study 5

Weights were not provided on the linked datasets (those matched to the health records). The unique identification numbers for each case were different on the interview and linked datasets, due to the process described in Appendix 5. I created a unique identification number based on the responses to seven variables (primary sampling unit, MVPA, age, height, sex, income, and household size). Using this, I matched the interview and linked datasets and transferred the weighting variables (see Figure 1 below). I then compared the weighted and unweighted age, sex, and MVPA-ST distributions of the analysis sample with that of the interview dataset (see Table 1 on following page). The interview dataset distributions are considered nationally representative and so it was preferable to match this as closely as possible.

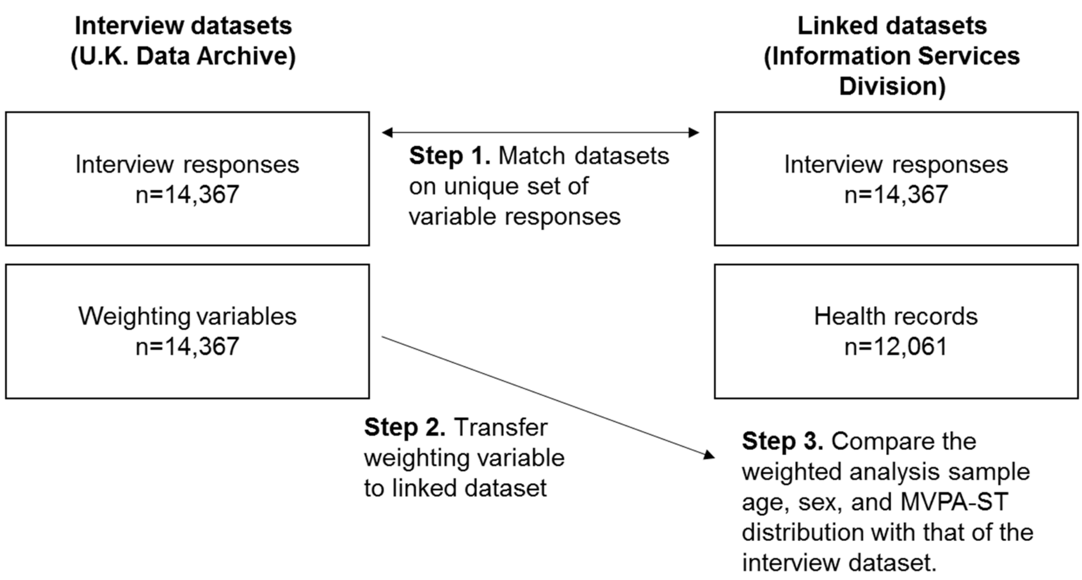


Figure 1. Transferring the weighting variables from the interview to the linked datasets.
Note. MVPA-ST = moderate-to-vigorous physical activity and sedentary time category. See Figure 26 in main thesis for explanation.

Table 1. Comparison of the Sex, Age, and Physical Activity and Sedentary Time Distributions of the Weighted and Unweighted Analysis Sample to the Weighted Interview Sample

	Interview sample, (%)	Analysis sample, (%)	
Covariate	Weighted n=14,367	Weighted n= 11,333	Unweighted n=11,481
Sex			
Male	48.0	47.1	43.4
Female	52.0	52.9	56.6
Age			
16-44	45.1	44.6	37.9
45-64	33.7	34.5	35.7
64-84	19.1	19.2	24.4
85+	2.0	1.7	2.0
MVPA-ST			
LowMVPA/HighST	9.4	10.1	10.7
LowMVPA/LowST	12.6	11.9	12.8
2ndMVPA/HighST	7.2	8.3	8.3
2ndMVPA/LowST	16.4	16.1	17.2
3rdMVPA/HighST	7.0	8.5	7.6
3rdMVPA/LowST	17.7	17.2	17.7
HighMVPA/HighST	6.8	4.9	4.1
HighMVPA/LowST	19.2	22.9	21.7
Missing	3.7	N/A	

Note. MVPA = moderate-to-vigorous physical activity; ST = sedentary time. See Figure 26 for explanation of the category abbreviations.

31. Supplementary table for Study 5

Supplementary Table 1. Associations Between MVPA-ST Category and All-cause Mortality, Cardiovascular Disease-related Events or Mortality, Malignant Cancer Diagnosis or Death, and Episodes with a Principal or Non-principal Diagnosis of Diabetes

Outcome, and exposure category	Events/n (Model 1[a])	Model 1		Model 2	
		HR	95% CI[b]	HR	95% CI[b]
All-cause mortality					
LowMVPA/HighST	65/1089	1		1	
LowMVPA/LowST	28/1390	0.44	(0.28, 0.69)	0.59	(0.37, 0.93)
2ndMVPA/HighST	7/863	0.33	(0.15, 0.72)	0.60	(0.28, 1.30)
2ndMVPA/LowST	14/1942	0.27	(0.16, 0.47)	0.59	(0.34, 1.03)
3rdMVPA/HighST	2/841	0.15	(0.06, 0.41)	0.36	(0.13, 0.98)
3rdMVPA/LowST	9/2083	0.20	(0.10, 0.39)	0.48	(0.24, 0.97)
HighMVPA/HighST	4/823	0.38	(0.15, 0.98)	1.16	(0.43, 3.16)
HighMVPA/LowST	3/2301	0.09	(0.04, 0.24)	0.28	(0.11, 0.72)
Cardiovascular disease-related events or mortality					
LowMVPA/HighST	26/1088	1		1	
LowMVPA/LowST	15/1390	0.66	(0.35, 1.24)	0.74	(0.39, 1.43)
2ndMVPA/HighST	9/863	0.87	(0.41, 1.85)	1.15	(0.52, 2.56)
2ndMVPA/LowST	9/1942	0.36	(0.17, 0.79)	0.52	(0.23, 1.20)
3rdMVPA/HighST	2/841	0.23	(0.03, 1.63)	0.32	(0.04, 2.34)
3rdMVPA/LowST	3/2083	0.14	(0.03, 0.56)	0.20	(0.05, 0.82)
HighMVPA/HighST	3/823	0.49	(0.09, 2.54)	0.76	(0.14, 3.99)
HighMVPA/LowST	2/2301	0.09	(0.02, 0.41)	0.15	(0.03, 0.71)
Malignant cancer diagnosis or death					
LowMVPA/HighST	44/1087	1		1	
LowMVPA/LowST	41/1390	0.89	(0.57, 1.40)	0.98	(0.62, 1.54)
2ndMVPA/HighST	14/863	0.71	(0.38, 1.33)	0.82	(0.43, 1.56)
2ndMVPA/LowST	30/1942	0.65	(0.40, 1.06)	0.82	(0.50, 1.36)
3rdMVPA/HighST	13/841	0.93	(0.47, 1.82)	1.11	(0.55, 2.26)
3rdMVPA/LowST	29/2083	0.68	(0.41, 1.13)	0.86	(0.49, 1.50)
HighMVPA/HighST	9/823	0.86	(0.30, 2.45)	1.06	(0.37, 3.03)
HighMVPA/LowST	18/2301	0.48	(0.26, 0.89)	0.60	(0.31, 1.17)

Events with a principle or non-principle diagnosis of diabetes					
LowMVPA/HighST	56/1088	1		1	
LowMVPA/LowST	30/1390	0.50	(0.31, 0.78)	0.64	(0.40, 1.03)
2ndMVPA/HighST	10/863	0.34	(0.18, 0.65)	0.52	(0.27, 1.00)
2ndMVPA/LowST	14/1942	0.19	(0.11, 0.35)	0.40	(0.21, 0.76)
3rdMVPA/HighST	9/841	0.38	(0.16, 0.91)	0.81	(0.34, 1.96)
3rdMVPA/LowST	14/2083	0.21	(0.11, 0.38)	0.47	(0.24, 0.92)
HighMVPA/HighST	1/823	0.07	(0.02, 0.32)	0.18	(0.04, 0.81)
HighMVPA/LowST	6/2301	0.10	(0.05, 0.23)	0.27	(0.11, 0.66)

Note. CI = confidence interval; HR = hazard ratio; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. See Figure 26 for explanation of the MVPA-ST category abbreviations. Model 1: unadjusted; Model 2: adjusted for sex, deprivation, economic activity status, self-reported health, smoking status. Weighted n for Model 1 ranged between 11,334-11,332 dependent on individuals with event on day of interview; Model 2 ranged between 11,297-11,298 due for the same reasons and missing data in covariates. Age was used as the time-scale. [a]May not match total weighted sample size due to rounding; [b]Confidence intervals calculated using Taylor-Series linearisation variance estimation techniques.