SARCOPENIA, MOBILITY, AND 24H MOVEMENT BEHAVIOURS IN SOUTH AFRICAN AND SCOTTISH OLDER ADULTS ACROSS DIFFERENT SOCIOECONOMIC SETTINGS

Ilaria Pina

A thesis submitted to the University of Stirling in fulfilment for the degree of Doctor of Philosophy
Psychology Division, Faculty of Natural Sciences

University of Stirling

June 2021

Declaration

I declare that this thesis was composed by myself, under the supervision of Dr Angus Hunter, Dr Rachel Crockett, and Dr Paul Dudchenko. Neither the thesis, nor the original work contained therein have been submitted to this or any other institution for a higher degree.

Ilaria Pina

Student ID: 2639222

Stirling, 29/06/2021

Submission for Viva examination: 29/06/2021

Viva examination date: 06/10/2021

Thesis approved for final submission: 22/03/2021

Acknowledgments

First and foremost I would like to thank my Supervisors Dr Angus Hunter, Dr Rachel Crockett, Dr Paul Dudchenko, and my Honorary Supervisor Dr Simone Tomaz whose efforts throughout the past years have helped me grow as an individual. I will always be grateful for believing in me and spending time on my professional development, this thesis would not have been possible without your continuous support.

A BIG thank you to the staff at the University of Stirling. Particularly, thank you to Ms Gillian Dreczkowski and Mr Chris Grigson, who have always been available to help or, none the less, offer a sympathetic ear during hard time of data collection. Thank you to Dr Lewis Macgregor, Dr Naomi Brooks, and Dr Iain Gallagher for their amazing guidance and the patience in teaching me how to use new equipment during this PhD experience. I would also like to thank all volunteers who participated in the project.

This project would not have been possible without the support of the team based at the University of Cape Town. Thank you to Dr Amy Mendham and Professor Julia Goedecke. Amy, I feel honoured to call you a friend. It was an absolute privilege to work with both of you, and I was lucky to benefit so greatly from your knowledge and experience.

To my parents, Loredana and Silvano, who provided me with endless support and faith throughout my whole University studies. The truth is I would not be here without your sacrifice and help. Thanks for always supporting me.

Although almost at the end of the page, thanks to my (new) husband, Gianmaria. I feel privileged to call you husband at the end of this PhD journey. You have always been there for me, even when you had better run away. You believed in me more than everyone else during the past 9 years. Thanks for your never-ending support and love. *Potrei vivere diverse migliaia di vite e mai meritare il tuo amore.*

General abstract

Mobility relates to the basic human need of physical movement which declines with advancing age. Strong evidence of successful ageing can be found in mobility performance (walking, muscle strength, and physical functioning) evaluation. Previous evidence indicates that physical activity could prevent progression of mobility limitation and promote successful ageing. As such, the overall aim of this thesis is to determine effects of 24-h movement behaviours (physical activity, sedentary behaviour, and sleep) on musculoskeletal health, adiposity, and physical functioning in older adults. Chapter 1 reviews the evidence for these outcomes of interest. Subsequently, chapter 2 reports on changes in walking behaviour with increasing age in high-functioning older adults living in Scotland. However, individual intrinsic capacity is only one of the components of functional mobility and laboratory-based gait analysis can only provide a limited picture. Accordingly, in chapters 3-5, laboratory-based measurements of mobility have been translated into the real world by considering movement within the whole 24-h time period in older adult populations living in Scotland (high-income setting) and South African Townships (low-income setting). Chapter 3 describes compositional time differences in 24-h movement behaviour between Scottish and South African older adults. Chapters 4 and 5 investigates associations between 24-h movement behaviours, musculoskeletal health, adiposity, and physical functioning. Higher volumes of moderate- to vigorous-intensity physical activity were associated with better health outcomes in both samples, while sedentary behaviour presented a detrimental effect on other variables. However, differences in health outcomes associations were present between the Scottish and South African settings. The findings reported in this thesis demonstrates the importance of exploring 24-h movement behaviours in older adults from differing settings, to gain greater understanding of context and socioeconomic profiles, and how these link to health outcomes so that there is an understanding of how best to intervene.

Table of Contents

Publication(s)

Pina, I., Mendham, A. E., Tomaz, S. A., Goedecke, J. H., Micklesfield, L. K., Brooks, N. E., ... & Hunter, A. M. (2021). Intensity Matters for Musculoskeletal Health: A Cross-Sectional Study on Movement Behaviours of Older Adults from High-Income Scottish and Low-Income South African Communities. International journal of environmental research and public health, 18(8), 4310. **(Chapter 3 and 4)**

List of Conference and Poster presentations

Pina I., Macgregor, L., Crockett, R., Dudchenko, P., Hunter, A.M. Changes in free normal walking and memory perception in ageing. *Oral Presentation and Poster Session, 4th Annual Scottish Dementia Research Consortium Conference - Glasgow, United Kingdom, April 2018.*

Pina I., Macgregor, L., Crockett, R., Dudchenko, P., Hunter, A.M. Gait analysis for different terrains in younger and older adults. *Poster Session, Clinical Movement Analysis Society of UK and Ireland – Sheffield, United Kingdom, April 2019.*

Pina, I., Mendham, A. E., Goedecke, J. H., Tomaz, S. A., Crockett, R., Dudchenko, P., Hunter, A. M. (2021). Intensity matters: movement behaviours of older adults from high-income Scottish and low-income South African communities. *Oral Presentation, UK Society of Behavioural Medicine ECN Webinar – Virtual, October 2020 [top 3 abstracts].*

Pina, I., Hunter, A.M., Tomaz, S.A., Ryde, G., Coffee, P., Connelly, J., Kirkland, A., McCabe, L., Watchman, K., Andreis, F., Neely, K.C., Swales, B., Martin, J.G., Whittaker, A.C. Changes in Scottish older adults physical activity:"…although I walked before the crisis I have made a habit of walking every morning". *Poster Session, Scottish Physical Activity Research Connections (SPARC) - Virtual, November 2020.*

List of figures and tables

Figure 16. Positioning for whole body measurements with DXA.

Figure 17. Grip strengthBMI value according for men and women to sleep quality score (poor sleep quality defined as overall score >5). Statistically significant results p<0.05*.

Figure 18. Odd ratios (95% CI) per unit change of overall PSQI score and self-rated sleep quality for low bone mineral density in the Scottish sample (a), sarcopenia in the Scottish sample (b), for low bone mineral density in the South African sample (c), and sarcopenia in the South African sample (d). Abbreviations: BMD, bone mineral density. PSQI, Pittsburgh Sleep Quality Index. Low bone mineral density defined as t-score<-1.5; sarcopenia according to FNIH cut off. Crude: age, sex; adjusted: age, sex, education, smoking status, total weekly PA models are shown.

Figure 19. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by group of waist circumference for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

Figure 20. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by BMI group for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

Figure 21. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by blood pressure group for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

Figure 22. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by group of waist circumference for South African older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

Figure 23. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by BMI group for South African older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

Table 18. Difference (95% CI) in grip strength, ASM, femoral neck BMD, hip total BMD, and lumbar spine BMD per unit change of sleep parameter in the South African cohort

Table 19. Adiposity, blood pressure, and physical functioning measures for Scottish and South African cohorts

Table 20. Compositional linear regression for the associations between movement behaviours, adiposity, blood pressure, and physical functioning outcomes in the Scottish cohort

Table 21. Compositional linear regression for the associations between movement behaviours, adiposity, blood pressure, and physical functioning outcomes in the South African cohort

Table 22. Subsample analysis for compositional linear regression for the associations between movement behaviours and musculoskeletal outcomes

List of abbreviations

ASM, appendicular skeletal muscle mass

BF, biceps femoris

BMC, bone mineral content

BMD, bone mineral density

BMI, body mass index

CoDa, compositional data analysis

CV, coefficient of variation

DXA, dual-energy X-ray absorptiometry

EWGSOP, European Working Group on Sarcopenia in Older People

FFQ, food frequency questionnaire

FFSM, fat-free soft tissue mass

FNIH, Foundation for the National Institutes of Health

GC, gait cycle

GL, gastrocnemius lateralis

GM, gastrocnemius medialis

HCS, Hertfordshire Cohort Study

HICs, high income countries

HIV, human immunodeficiency virus

ISCD, International Society for Clinical Densitometry

LMICs, low-middle income countries

LPA, light physical activity

MVPA, moderate-to-vigorous physical activity

NCDs, non-communicable diseases

NHANES, National Health and Nutrition Examination Survey

NSF, National Sleep Foundation

OR, odds-ratio

PA, physical activity

PSQI, Pittsburgh Sleep Quality Index

SAMRC, South African Medical Research Council

SB, sedentary behaviour

sEMG, surface electromyography

SES, socioeconomic status

TA, tibialis anterior

TiB, time in bed

TUG, timed up and go test

VL, vastus lateralis

VM, vastus medialis

WC, waist circumference

WHO, World Health Organisation

Chapter 1: Introduction and aims

1.1 Introduction and definition of concepts

Current demographic trends indicate that by 2050, one in six people in the world will be over 65 years old (United Nations 2019b), with the number of older adults and years lived with disabilities increasing worldwide. Musculoskeletal disorders and obesity are a major health problem for older adults leading to reduced mobility and subsequent severe effects on health and well-being (Briggs et al., 2016; Fontaine et al., 2003). A healthy musculoskeletal system and body composition are vital for daily physical functioning and for successful ageing, during which an individual can maintain better later life independence and quality of life. Indeed, strong evidence of markers of successful ageing can be found in the evaluation of mobility performances (i.e., walking speed and muscle strength) (Anton et al., 2015). Primary features of musculoskeletal ageing include decreased bone and muscle health, which contribute to reduced quality of life and loss of mobility (Curtis et al., 2015). Consequently, objective measurements of gait analysis would help to gain a better understanding of age-related changes and decline in older adults. Additionally, advancing age is associated with changes in body composition. Previous evidence highlighted a shift toward higher fat mass and reduced muscle mass (Pi-Sunyer, 2019), leading to an increased risk of obesity and chronic diseases as hypertension and diabetes (Decaria et al., 2012). Additionally, a recent study found that markers of obesity were consistently associated with poor physical performance in older adults (Kim et al., 2017). Thus, understanding age-related patterns of body-composition can progress our potential to develop appropriate strategies to optimize body composition for health and function in older adults.

However, individual intrinsic capacity is only one of the components of functional mobility in older people and laboratory-based gait analysis can only provide a limited picture. Accordingly, laboratory-based measurements of mobility should be translated into the real world by considering movement within the whole 24-h time period. Indeed, the environment, socioeconomic status, and neighbourhood are major predictors of older adult movement behaviours and health status (Pickett & Pearl, 2001). Different environments can provide various resources or barriers determining engagement in activities as walking and leisure physical activity (PA) (Kepper et al., 2019). For example, low- and middle-income countries (LMICs) are often characterised by greater degrees of poor and overcrowded environments, lack of safety, and inaccessibility to recreational facilities for PA (Lambert et al., 2020). Thus, in areas of disadvantage within

LMICs, PA is often performed mainly for transport purposes and occupational activities at a low intensity (Gradidge et al., 2014). Conversely, high-income countries (HICs) have a greater burden of sedentary behaviour (SB) driven by high rates of work-related sitting time and screen time (Leitzman, 2018). Therefore, assessing and comparing these movement behaviours is important as low PA levels are recognised as potential underlying mechanisms of musculoskeletal disorder and associated cardiometabolic disease. Thus, the purpose of the literature review is to explore the relationship between movement behaviours, musculoskeletal health, body composition, and physical functioning in older adults living in HICs and LMICs.

1.2 Gait

Gait is the characteristic pattern of limbs movement during locomotion. It is generally performed automatically, requiring specific cognitive functions (Leisman et al., 2016), motor patterns (Cappellini et al, 2006), and the ability to meet environmental demands (i.e. walking on uneven terrain) along with balance maintenance. Gait cycle is divided in 8 functional phases and these define the performance of one limb (Perry & Burnfield, 1993), while the other limb repeats the same motion sequence starting at 50% of a gait cycle later. One of the main mobility issues in older adults is to adapt their gait to the given terrain and conditions to avoid falls and save energy cost. Gait, particularly gait speed, is also an integrative measure of health and functionality (Studenski et al., 2011). Age-associated changes in health domains often manifest in gait alterations, including gait speed, temporal parameters, and their variation when dealing with uneven surfaces (Hausdorff, 2007). Measurements of gait phases will be described in Chapter 2. Walking is an easy to perform, convenient form of daily physical activity which can be carried out at light, moderate or vigorous intensity. Walking is the most commonly reported activity in older adults (Mobily, 2014; Ory et al., 2016), with also more than 40% of the activity counts measured with an accelerometer for 2 weeks in healthy and independently living older adults (Valenti et al., 2016). However, walking is a complex motor task often no longer performed automatically by older adults. Important changes occur in gait across the life span, particularly after the age of 70, with older adults requiring higher attention and motor control than younger adults (Bridenbaugh & Kressig, 2011; Ciprandi et al., 2017). Therefore, gait changes could be considered as relevant predictors and risk factors for falls and reduced engagement in physical activities in older adults.

1.3 Movement behaviours

Movement behaviours include all activities over a 24-h period across the movement spectrum, from no/little movement (sleep, sedentary behaviour) to movement of greater intensities (light and moderate-to-vigorous PA). Traditionally, health implications of time spent in each of these movement behaviours have been examined in isolation or with only partial adjustment for time spent in other movement behaviours. However, evidence indicates that an integrated approach, which considers the co-dependence of all movement behaviours, is more informative on health outcomes compared to approaches considering single behaviours (Figure 1) (Chaput et al., 2014). This idea is further supported by the development of new 24-h movement guidelines in different countries. For example, Canada (HIC) developed and released in 2020 the first 24-hour movement guidelines for adults and older adults (Ross et al., 2020). Additionally, other countries, including South Africa, published 24-h movement guidelines for the Early Years (birth-5 years) (Draper et al., 2020). The World Health Organization (WHO) recently introduced physical activity and sedentary behaviour guidelines for adults of all ages (Bull et al., 2020). These differ from previously published guidelines for older adults (from the WHO and elsewhere, including the UK (UK Chief Medical Officers, 2019)) as these consider movement throughout the day. Thus, investigating the combination of behavioural activities contributing to healthy body composition and functional maintenance can help the development of future interventions targeting mobility and physical independence in older adults. Measurements of 24-h movement behaviours will be described in Chapter 3.

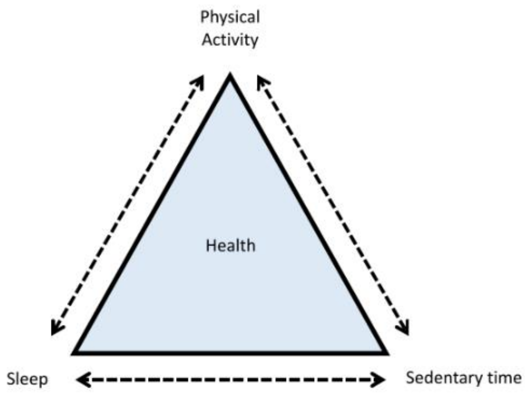


Figure 1.Co-dependence of movement behaviours in the 24h spectrum (Chaput et al., 2014).

1.3.1 Physical activity

PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure and can be performed at a variety of intensities (Caspersen et al., 1985). Recently, a more holistic approach to defining PA has been suggested with the consideration of people moving, acting, and performing within culturally specific spaces and contexts, and influenced by interests, emotions, ideas, and relationships (Piggin, 2020). The former definition provides a more biomedical and quantitative approach which contributed to the development of technologies to assess objectively measured (device-based) PA while the definition from Piggin accounts for the complex nature of PA by considering a more qualitative approach which is rarely captured in the objectively measured PA field. PA can be accumulated through engagement in various activity domains: work (occupational), household (domestic), transportation, and leisure (Strath et al., 2013). According to the most recent WHO guidelines, in a 24-h day, older adults should do at least 150–300 minutes of moderate-intensity aerobic physical activity; or at least 75–150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity throughout the week. Older adults should also do muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups on 2 or more days a week (Bull et al., 2020). Measurement of movement behaviours comprises two constructs: the behaviour (PA, SB, and sleep) and the physiological consequence of the behaviour (energy expenditure) (LaMonte & Ainsworth, 2001). The choice of how to measure these constructs varies in feasibility and accuracy. Self-reported measures include standardised questionnaires, diaries, and logs are the most common method for measuring PA levels (Adamo et al., 2009) due to low cost and minimal participant burden (Dishman et al., 2001). However, limitations to this approach are present such us social desirability bias, with individuals found to overreport levels of PA and underestimate time spent sedentary (Adamo et al., 2009). For example, the proportion of US adults found to meet activity guidelines was 62% based on self-report and around 10% for device-based measure (Tucker et al., 2011). Additionally, population literacy should be considered in both HICs and LMICs. Indeed, it is reported that up to 15% of adults in the UK are illiterate, with that proportion increasing in older adults (Wolf et al., 2005). Additionally, in LMICs low coverage of telephone lines and internet in several areas makes it unfeasible to include these instruments (Hallal et al., 2012). Researchers also rely on objective measurements of PA with accelerometers more often worn on the waist, wrist or lower limbs measuring the acceleration produced on one (uniaxial), two (biaxial) or three (triaxial) planes (Welk, 2002).

1.3.2 Sedentary behaviour

Sedentary behaviour (SB) is defined as any waking behaviour characterised by low energy expenditure (between 1.0 and 1.5 metabolic equivalents) while in a sitting, reclining, or lying posture (Tremblay et., 2017), it has been operationalised as low counts on activity monitors (i.e. accelerometer) (Dempsey et al., 2020). SB can be described according to the duration (time), bout (period of uninterrupted sedentary time) and breaks (a non-sedentary bout in between sedentary bouts) (Tremblay et al., 2017). Previous evidence demonstrated that SB has specific physiological and health implications which differ from those attributable to physical inactivity (Tremblay et al., 2010). Therefore, it has been considered as a distinct behaviour with a standardised conceptual model which require specialised assessment and interpretation (Tremblay et., 2017). Similarly to PA, measurement of SB involves the use of self-reported (questionnaires categorised by posture and energy expenditure) and objective methods (such as inclinometers and accelerometers) (Leitzmann et al., 2017) and should consider validity, reliability, and responsiveness of a method for the population and context. Common SB activities in adults and older adults include television (TV) viewing, computer use, driving, and reading (Leitzmann et al., 2017). However, recent studies found that specific type of sedentary behaviours can be differently associated with health outcomes. Sedentary behaviours could be "mentally active" characterised by cognitive effort (using a computer, reading, car driving, attending a meeting, knitting, or sewing), whereas others are defined "mentally passive" as they primarily involve passive mental activities (watching TV, talking and sitting) (Kikuchi et al., 2014; Huang et al., 2020). Understanding how different types of SB are related to health is relevant to older adults, who tend to spend longer time in SB (Clark et al., 2010).

Current UK and WHO guidelines for adults and older adults highlight the need to limit time spent in this behaviour (UK Chief Medical Officers, 2019). Additionally, 24-h movements guidelines from Canada suggest limiting sedentary time to 8 hours per day or less, including no more than 3 hours of recreational screen time and breaking up periods of sittings as often as possible (Ross et al., 2020). Changes in the amount of time spent in one movement behaviour that comprise a 24-h day will affect the amount of time spent in other behaviours. Indeed, studies investigating the combined effect of 24-h movement behaviours on health in adults and older adults highlighted that the whole 24-h day is associated with different health outcomes (Rollo et al., 2020). Thus, this evidence demonstrated the importance of applying a 24-h approach on movement behaviours.

1.3.3 Sleep

In the Thesis, sleep will be considered as time spent in bed during nights (nocturnal sleep) measured with hip worn tri-axial accelerometer. Sleep is usually differentiated in two components: sleep quantity and quality. Sleep quantity includes quantifiable characteristics such as sleep duration, sleep latency, sleep efficiency, and number of awakenings (Pilcher et al., 1997). This component is usually measured with objective methods such as cardiorespiratory polysomnography (gold-standard) and wrist-worn actigraphy (Zinkhan et al., 2014). Sleep quality includes mainly subjective indices of sleep, such as satisfaction with sleep and how well rested one feels upon awakening (Pilcher et al., 1997). Several sleep questionnaires with self-reported sleep characteristics have been widely used in studies with older adults to assess sleep quality, especially for feasibility reasons. However, previous research has found discrepancies between subjective reports and objective measures of sleep, with older adults perceiving more severe sleep disturbances than results from objective measures (Kay et al., 2015; Williams et al., 2013). Additionally, a study showed that the agreement of sleep parameters monitored by polysomnography and tri-axial accelerometer placed at the wrist was superior to the assessment of those parameters by hip-worn monitor (Zinkhan et al., 2014). Therefore, future research should consider the possibility of having a combination of subjective and objective sleep measurements in older adult populations. Recommendations on sleep duration are provided by the National Sleep Foundations (NSF) (Hirshkowitz et al., 2015) and are different for adults (26-64 years) and older adults (65+) (**Table 1**).

Table 1. National Sleep Foundations guidelines on sleep duration

	Adults (<65y)	Older adults (≥65y)
Meeting recommendations	Between 7 and 9h	Between 7 and 8h
Within the appropriate sleep range	Between 6 and 7h; or between 9 and 10h	Between 5 and 7h; or between 8 and 9h
Sleeping too little (short sleepers)	Less than 6h	Less than 5h
Sleeping too much (long sleepers)	More than 10h	More than 9h

1.4 Muscle mass and muscle strength

Muscle health is a relevant determinant for mobility during ageing. Skeletal muscle mass, specifically the number and size of muscles fibres, declines at a rate of approximately 0.8% per year, starting from the 4th decade of life (Tieland et al., 2018). While estimates of the age-related rate of muscle strength loss are reported to be higher compared to the decline in muscle mass, at 1-3% per year (Keller & Engelhardt, 2013). Loss of muscle function negatively affects functional independence and reduces quality of life in older adults. Additionally, recent research indicated that the excess health care costs of muscle weakness are £2.5 billion per year, with £1.3 billion per year for health care alone (Pinedo-Villanueva et al., 2019). Consequently, with the world's population of people aged 60 years and older being 2.1 billion by 2050 (United Nations 2019b), the socioeconomic burden of muscle loss with ageing is projected to increase. A previous study observed that for the year 2000, in the United States, the direct health care cost attributable to sarcopenia was estimated at $18.5 billion (1.5% of the total healthcare expenditure) (Janssen et al., 2004). A recent systematic review also reported trends toward a more important use of healthcare resources in the sarcopenic population (Bruyère et al., 2019).

Muscle mass is normally identified as fat-free soft tissue mass (FFSTM) and it is usually measured with dual-energy X-ray absorptiometry (DXA). This is a non-invasive and safe (low levels of radiation) procedure to determine muscle mass (Cruz-Jentoft et al., 2019). The most recent European Working Group on Sarcopenia in Older People (EWGSOP) and Foundation for the National Institutes of Health (FNIH) algorithms to assess sarcopenia suggest using appendicular skeletal muscle mass (ASM) adjusted for body composition as determinant of muscle mass (Cruz-Jentoft et al., 2019; Studenski et al., 2014). ASM is defined as the sum of FFSTM (kg) of both legs and arms and later adjust values for Body Mass Index (BMI).

Muscle strength is defined as the ability of a muscle or muscle group to exert a maximal force or torque at a specific velocity during a muscle contraction (Buchner & de Lateur, 1991). The most common measure of muscle strength in older adults is grip strength. It has been commonly adopted as an indicator of general muscle strength and recent evidence highlighted the role of grip strength as a biomarker for both current and future health status in older adults (Bohannon, 2019). It is normally measured with calibrated handheld dynamometer under well-defined testing protocol.

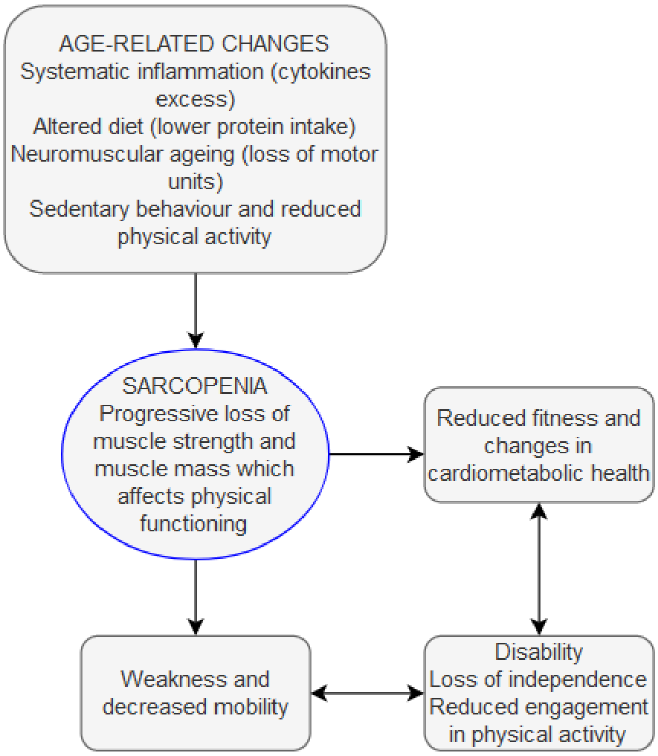


Figure 2. Model for sarcopenia onset and progression.

Decline in muscle strength and muscle mass are the main determinants of sarcopenia. In the most recent consensus in 2018, the EWGSOP (Cruz-Jentoft et al., 2019) and previously in 2014 the FNIH Sarcopenia Project (Studenski et al., 2014) defined sarcopenia as a progressive and generalised skeletal muscle disorder that affects physical functionality identified by low muscle strength, along with decreased muscle mass. Diagnosis of sarcopenia is based on the presence of low muscle strength along with presence of low muscle mass (Cruz-Jentoft et al., 2019). When low muscle strength, low muscle mass and low physical performance are all detected, the disease is considered severe (Cruz-Jentoft et al., 2019). Muscle strength is assessed with grip strength or chair stand test (5-times sit-to-stand), while skeletal muscle mass is classified according to ASM measured via dual-energy x-ray absorptiometry (or magnetic resonance imaging, or mid-thigh muscle cross-sectional area by computer tomography). Lastly, physical performance is assessed with gait speed or timed-up-and-go test (Cruz-Jentoft et al., 2019). Sarcopenia affects older individuals through reduction in ability to complete activities of daily living due to decreased total strength and exercise performance. As a consequence, it is becoming a growing global health concern as it is significantly associated with self-reported physical disability in both men and women, deterioration of respiratory function, metabolic health, falls and mobility impairments (Janssen et al., 2002). A multifactorial age-related aetiology is considered to play a key role in causing this neuromuscular disorder (**Figure 2**); one mechanism, particularly, that can lead to sarcopenia is the loss of motor units (Piasecki et al., 2018). A recent review highlighted the role of neural control of skeletal muscle as a key contributor to declining muscle and physical function in older adults (Clark, 2019), providing evidence of neuromuscular changes occurring along with muscle mass decline (Piasecki et al., 2016). Indeed, low muscle strength is the primary parameter and most reliable measure of muscle function as intrinsically related to neurological decline.

1.5 Bone mineral density

Bone mineral density (BMD) is a measurement of the bone mineral content (BMC) per unit of bone area, and low BMD is used clinically to identify individuals with osteoporosis and at high risk of fracture. Osteoporosis is a multi-factorial disorder involving decreased bone mass and changes in bone integrity with deterioration of bone tissue and disruption of its architecture (Nielsen et al., 2018). Specifically, an imbalance in bone remodelling is present, with an excess of osteoclast reabsorption compared to osteoblasts production of mineralised extracellular matrix to rebuild the resorptive cavity (Brown, 2017). Preferred skeletal site to assess BMD are the femoral neck, whole hip, and lumbar spine with DXA scan. Specifically, the International Society for Clinical Densitometry (ISCD) guidelines for adults aged ≥50 years were recently updated to determine adults with osteoporosis. This is defined as a t-score lower than 2.5 at one or more of skeletal sites mentioned above (Looker, 2012; Shuhart et al., 2019). The T-score value is a comparison of a person's bone density with that of a healthy 30-year-old of the same sex.

Recent studies investigated crosstalk between muscle and bone tissues due to their shared environment (Yakabe et al., 2020). Previous evidence observed changes in muscle and bone muscle associated with PA, disuse, and ageing process (Hamrick, 2010) according to the mechanostat theory where muscle is recognised as source of mechanical stimuli for bone tissue (a decline in mechanical loading from muscle can reduce bone formation) (Edwards et al., 2015; Kaji, 2014, Sharir et al., 2011). Muscle and bone tissues also share a connection between humoral factors such as myokines (secreted from skeletal muscle cells) and osteokines (secreted from osteocytes) (Sharir et al., 2011). However, the precise mechanisms responsible for bone and skeletal mass metabolism are still not well-characterized. Recent data support the idea that muscle and bone tissue secrete factors targeting other tissues and are involved in glucose metabolism (Schafer et al., 2016). This interplay between muscle and bone supports the idea that the mechanical load produced by PA via muscle contraction shapes bone structure and maintains bone mineral density (BMD) and overall integrity with ageing. There is growing evidence of a positive association between bone and muscle metabolism which could be considered as a whole unit (Yakabe et al., 2020).

1.6 Adiposity and body composition

Obesity is defined by the WHO as abnormal or excessive fat accumulation that could impair overall health (World Health Organisation, 1998). WHO recommends to consider body mass index (BMI) as the most useful population-level measure of obesity, defined as a BMI greater than or equal to 30 (World Health Organisation, 1998). However, evidence highlights the presence of unfavourable changes in body composition with ageing. Specifically, accumulation and redistribution of fat (especially abdominal fat and ectopic fat deposition in skeletal muscle) and loss of lean mass have been observed in older adults (Pi-Sunyer, 2019). Abdominal adiposity is a relevant predictor for poor overall health, reduced functional capacity and quality of life in older adults (Morgan et al., 2020). Additionally, it is associated with compromised muscle quality (Scott et al., 2018) and does not appear to provide any protective effect on bone health (Leslie et al., 2014). Examples of reliable and commonly used anthropometric measurements include waist and hip circumferences (Kim, 2016) as marker for abdominal obesity in older adults. Fat mass and lean mass are often included in research and measured via DXA (Kim, 2016). Levels of global obesity and increased adiposity are on a progressive rise (Peeters & Backholer, 2012) and the related health burden will continue to increase due to presence of concurrent disabling condition such as sarcopenia and osteoporosis. Therefore, there is the urgent need to assess the effect of the combination of 24-h movement behaviours on these health outcomes.

1.7 Socioeconomic status

Socioeconomic status (SES) can be defined in terms of individual (economic situation or educational status), household, and neighbourhood characteristics (Baker, 2014). From previous evidence, a consistent association emerges between SES and health (Shavers, 2007; Herd et al., 2007). Although there is no consensus on the origins of the socioeconomic gradient in health, one of the suggested pathways involves higher prevalence of unhealthy behaviours among lower socioeconomic settings (Adler et al., 1994). Specifically, SES is frequently assessed as a correlate of both movement behaviours and health outcomes. Additionally, LMICs are often characterized by both a higher prevalence of obesity (Shisana et al., 2014), communicable, and non-communicable diseases (Mafuya et al., 2013) compared to HICs (Scottish Health Survey, 2019). Differences in living conditions and sociodemographic factors contribute to greater exposure and vulnerability of low socioeconomic communities to chronic diseases and unhealthy behaviours (Mayosi et al., 2009), leading to differences in general health status across socioeconomic settings. However, little is known on how differences in health status and movement behaviours in LMICs and HICs can affect musculoskeletal health, body composition, and adiposity of men and women living in these settings.

1.2. How does ageing and socioeconomic status affect mobility and movement behaviours?

1.2.1 Search strategy

Given the importance of the 24-h movement behaviour pattern and functional mobility in older adults, the relationships between movement behaviour compositions and health outcomes may change as a function of the socioeconomic setting. Therefore, it is important to review existing evidence for the associations between 24-h movement behaviours and health outcomes in older adults living in different income communities. Specifically, the purpose of this review was to examine the relationships between the combinations of PA, SB, and sleep with musculoskeletal health, adiposity, and physical functioning outcomes in older adults aged 60+ (Rault, 2019). Where literature was available for Scottish and South African samples, this literature was prioritised, and where there was little/no evidence from

Scotland/South Africa, the search was expanded to other countries with similar profiles (United Kingdom/Europe, Sub-Saharan Africa/Africa). The literature search was performed with the following databases: Google Scholar, PubMed, Web of Science, and Scopus. Search terms included in the search strategy were: 1) "movement behaviours", "mobility", "physical activity", "sedentary behaviour", and "sleep"; in combination with 2) "older adults", "elderly"; and 3) "socioeconomic status", "high income", "low-middle income"; and 4) "sarcopenia", "muscle mass", "muscle strength", "grip strength"; and 5) "bone mineral density", "bone health"; and 6) "adiposity", "body mass index", "blood pressure", "obesity", "fat mass".

1.2.2.2 Gait

Gait is an integrative measure of mobility and general health, particularly in older adults as it has been shown to be a determinant of multiple health outcomes as risk of falling (Maki, 1997), cognitive decline (Verghese et al., 2007), and mortality (Studenski et al., 2011). Additionally, walking is increasingly recognised as a relevant component of PA in older adults. However, individuals from lower SES tend to walk mainly for transportation and less for recreation than higher SES individuals (Gradidge et al., 2014; Strain et al., 2020). Healthy ageing impacts walking behaviour on different aspects as joint mobility, muscle strength, balance, and walking speed (Beauchet, 2017). Gait changes, particularly the decrease in walking speed, are important markers of overall functional independence and mobility during ageing, able to predict future disability (Artaud et al., 2015). Additionally, a functional gait must ensure the capacity of dealing with different types of surfaces. Therefore, it is important to measure age-related changes in walking behaviour across different surfaces in the adult life span (18+) with an ecologically valid laboratory-based gait analysis approach.

Previous studies (Schmitz et al., 2009) comparing young vs older adults walking behaviour found an increased reliance on hip muscles for power generation and decreased ankle ranges of motion. Additionally, in older adults walking can become less automatic and start requiring higher cognitive attention to motor control (Yogev-Seligmann et al., 2008). Changes in walking pattern are also due to muscular impairments from a loss of muscle strength and alterations in muscle mass, closely related to muscle failure (Pijnappels et al., 2008). Most spatiotemporal parameters are affected by ageing, with older adults reducing their preferred walking speed, cadence, and stride length. Conversely, temporal parameters as double support, stride time, and stance time show an increase when compared to young adults (Herssens et al., 2018). However, a recent review highlighted the lack of data concerning changes in walking for middle-aged adults (Herssens et al., 2018). Therefore, identifying the onset of changes in walking behaviour such as normal walking and obstacle negotiations during adult life span could have a key role in predicting future functionality and mobility in older adults.

1.2.3.3 Physical activity

PA participation generally declines with ageing, with older adults consistently being reported as the least physically active age group (Sun et al., 2013). Globally, more than a quarter of adults are physically inactive (defined as not meeting WHO PA guidelines of 150 min of moderate- to vigorous-intensity physical activity (MVPA) per week) (Guthold et al., 2018). The decline in PA with age is one of the most consistent findings in PA epidemiology (Sun et al., 2013), along with males displaying higher PA volume than females (Guthold et al., 2018). Within the older adults age group, there is also consistent evidence that patterns of participation in PA decrease progressively with age for both men and women after the age of 65, although these trends displayed variations across studies (ranging from a difference of 10% to 35%) (Sun et al., 2013). In line with these findings, results from the Scottish Health Survey in 2019 showed that 45% of adults aged 65-74 years did not engaged in enough MVPA to achieve national PA recommendations (Scottish Health Survey, 2019). Additionally, physical activity levels declined with age, with 65% of older adults aged 75+ not meeting PA guidelines compared to their younger counterpart (Scottish Health Survey, 2019). Scottish older adults reported longer time spent in sedentary behaviour compared to younger age groups with a mean of 7 hours per day of sedentary time (Scottish Health Survey, 2019; Strain et al., 2018). Conversely, a smaller number of studies have focused on PA in older adults in South Africa, with a lack of nationally representative data. However, a previous randomised controlled trial with a 3 weeks culturally adapted theory-based intervention in South African men observed an increase in self-reported PA (Jemmott III et al., 2014). Results from a national survey in 2012, reported the 69% of South African adults aged 50+ as being physically inactive (Mlangeni et al., 2018; Tomaz et al., 2020). Additionally, this study also assessed age differences (from 40 to 90 years) and irrespective of domain, there was a trend for decreasing PA with older participants less physically active

(69% of older participants were physically inactive) and more sedentary than the younger age categories with physical inactivity levels ranging from 39% to 60% for 15-19 years old and 25-49 years old, respectively. However, these information on movement behaviours are from self-reported data. The main strength of PA self-reports is the cost-effective collection of information and the potential use in large-scale applications (Sattler et al., 2021). However, the use of self-reported measures of PA has several limitations. For example, recall and social desirability bias can occur, they need to be population specific, and PA questionnaires demonstrated low validity for assessing lifestyle physical activity (Strath et al., 2013).

Previous studies also focused the attention on correlates and barriers for PA participation in this age group. A recent review of qualitative studies on factors affecting older adults' participation in PA, highlighted that social influences, physical mobility limitations, health benefits of PA, motivation and beliefs are prominent factors (Barnett et al., 2017). Additionally, it should be considered that PA can be accumulated through engagement in various activity domains: work, household, transport, and leisure (Howley, 2001). Different PA domains have been demonstrated to differently affect mobility and general health during ageing. Research indicating the health benefits of PA is predominantly limited to the leisure domain (Holtermann et al., 2020). For example, increase in mid-life leisure time PA has been shown to reduce the risk of mobility impairment in older age (31% lower risk with vigorous PA), while occupational physical activity in mid-life showed a detrimental effect on mobility in old age with 23% higher risk of impairments for participants with vigorous occupational PA (Hinrichs et al., 2014). Therefore, when considering the importance of daily activities t for a real-world approach of the 24-h movement behaviours I decided to focus on older adults (60+), due to evidence highlighting the vulnerability of this age group to decline in PA participation.

1.2.3.1 Socioeconomic status

Among older adults, one key influence on inequalities in specific domain of PA participation is individual and household SES (Bauman et al., 2012). Previous evidence highlighted that adults in higher level of SES are not more physically active when considering volume of PA suggesting a lack of SES influence on volume of PA (Barr et al., 2020). In a recent review, less than half of the studies included found that individuals of higher SES were more physically active than their low-SES counterparts (Stalsberg & Pedersen, 2018). Differences are present in purposes and intensities at which PA is performed (leisure vs occupational/active travel) (Cerin et al., 2017). Specifically, the domain in which a consistent influence of SES is present are leisure PA and sport participation (Van Cauwenberg et al., 2018), as they appear to be mainly influenced by barriers including geographic location and socio demographics factors (Van Cauwenberg et al., 2018). Indeed, even if previous studies concluded that adults with higher SES were more active, when specific PA domains are considered (occupational and transport), an opposite association appeared, indicating that individuals from lower SES groups were more or similarly physically active (Barr et al., 2020). Additionally, there is evidence that PA participation is also associated with neighbourhood SES (Tucker-Seeley et al., 2009). This is due to an easier access to leisure facilities, walkable, and safe neighbourhoods with easy access to public transport and fewer barriers leading to a greater amount of leisure walking and moderate-to-vigorous PA (MVPA) in older adults in higher socio-economic settings (Barnett et al., 2017). Conversely, women residing in lower-SES neighbourhoods reported great energy expenditure but less engagement in MVPA, suggesting daily lifestyle activities (work or active travel) as major contributors to energy expenditure (Barr et al., 2020). Thus, when considering PA inequalities, difference in domains and intensities of PA should be considered across socio-economic settings. I aim to expand the research into the effects of 24-h movement behaviours on health by taking into account older adults from different income communities with existing differences in time allocation of PA domains and PA purposes.

1.2.4 Sedentary behaviour

Older adults are one of the most sedentary age groups, sitting for more than 60% (8.5-9.6 hours) of the waking day (Palmer et al., 2019). Older adults reporting less sitting time tend to have better mobility and age more successfully (Yen et al., 2017). Specifically, previous evidence showed higher levels of objectively measured SB associated with worst physical function outcomes (Manas et al., 2017). Indeed, national and international guidelines for movement behaviours now include specific recommendations to reduce SB for older adults (Ross et al., 2020; Bull et al., 2020). Recently, the importance of the context in which SB take place has been recognised, with researchers considering possible differences on health impacts of mentally “passive” forms of sedentary SB (e.g., watching TV) vs form of mentally “active” SB (e.g., computer use, reading) (Copeland et al., 2017). A recently developed model presents four common domains of SB: leisure, transport, household, and occupational (Owen et al., 2011). A previous study with objectively measured data on SB highlighted that household, leisure, and transport were key domains of prolonged sedentary activities in older adults (Leask et al., 2015). Particularly, leisure SB at home was the most frequent activity (70% of the average time), with 49% of being leisure SB and was responsible for almost half of total sedentary time in older adults compared to 7% of SB for social activities (Leask et al., 2015). Thus, to sustain beneficial effects that PA has on different health outcomes with ageing, older adults should be supported to maintain PA levels, while reducing SB.

1.2.4.1 Socioeconomic status

The focus on factors influencing SB has mostly been on individual level factors (biological, psychological, and behavioural), however the built, physical, and socioeconomic environments need to be considered (Chastin et al., 2015). Evidence of the SES influence on this behaviour is entirely dependent on the SB domain considered. For example, TV viewing and educational levels showed an opposite association (Bauman et al., 2018), conversely total sedentary time (both self-reported and objectively measured) has a positive association with education levels. For example, objectively measured SB is higher among English adults in higher socioeconomic groups compared to less privileged groups, who spent 64 minutes/day fewer in SB compared to the participants in high socioeconomic group (Stamatakis et al., 2014). Overall, previous studies showed that SES is one of the most significant factors among external determinants of SB. This emphasises the importance for future studies to include socio economic settings influences on SB.

1.2.5.5 Sleep

Sleep is one of the most important determinants of health outcomes in older adults (Li et al., 2017). However, sleep patterns vary with ageing. Age-related changes include alterations in sleep subjective perception, quality, and duration. Additional variations in sleep patterns are displayed in increased number of daytime naps, increase in the number of night awakenings, longer sleep latency (longer time taken to fall asleep), and a decline in sleep efficiency (percentage of time spent asleep while in bed) with advancing age (Gadie et al., 2017; Gooneratne et al., 2014).

Evidence shows that older adults are also less likely to self-report poor sleep quality than younger individuals, especially after controlling for comorbidities and health (Nebes et al., 2009). Sleep duration shows an inverse association with age, specifically total sleep time decreases from 6.5–8.5 hours a night for a young adult to 5-7 hours into older ages (Chaput et al., 2020; Chaput et al., 2018). However, lack of consistency in the number of sleeping hours for both self-reported and objectively measures is present, potentially due to differences in methodology, culture, and socio-economic status across populations considered. Indeed, previous studies reported a range from 7 to 10 hours/day of sleeping time in older adults (Peltzer, 2012; Adams, 2006) and there is limited research reporting objectively measured sleep in South African (low income) and Scottish (high income) older adults. Given this, I aim to objectively measure sleep duration within these communities.

1.2.5.1 Socioeconomic status

Overall, SES has been associated with sleep quality and duration in several populations (Pretorius et al., 2015). Indeed, previous data showed that sleep duration has an inverse association with SES, with adults from more deprived levels (measured with education levels) having longer nocturnal sleeping times (Mezick et al., 2008). For example, a former study investigated self-reported sleep habits in urban Black South Africans. Long self-reported sleeping times (8.75 ± 1.72 hours/day) were found, along with a high number of daytime napping (Pretorius et al., 2015: Peltzer, 2017). Additionally, in a study involving objectively measures of sleep quality, longer sleep latency and poorer sleep efficiency were found in adults from low socioeconomic settings (Mezick et al., 2008). Considering the subjective perception of sleep quality, a consistent socioeconomic gradient was found when both education level and income have been considered as SES determinants. Previous studies showed that individuals with higher level of education reported better sleep quality and the presence of an association between socioeconomic and sleep complaints (greater SES is associated with less sleep complaints) (Grandner et al, 2010). Existing evidence supports the need of including socioeconomic factors in research considering sleep duration and sleep quality. Thus, I expand this need by comparing sleep time and self-reported sleep quality across different income communities.

1.3. How do movement behaviours affect musculoskeletal health, body composition, adiposity, and physical functioning in older adults?

1.3.1 Physical activity

In previous studies, PA was positively associated with muscle mass and strength, specifically engaging in higher intensities (moderate to vigorous PA, MVPA) accounts for most benefits on musculoskeletal outcomes (Foong et al., 2016). Indeed, a recent systematic review and meta-analysis confirmed that habitual PA is protective against sarcopenia incidence in older adults, with PA reducing the odds of developing sarcopenia in later life (odds ratio [OR] =0.45; 95% confidence interval [CI] 0.37–0.55) (Steffl et al., 2017). Specifically, individuals meeting WHO recommendations displayed greater muscle mass (Steffl et al., 2017). In another study, high levels of MVPA in older adults were associated with both greater muscle mass and strength, with generally lower rates of sarcopenia (Foong et al., 2016). This finding is further supported by a randomised controlled trial with a PA intervention (aerobic, strength, flexibility, and balance training with walking as primary mode of PA) involving older adults. Indeed, the trial observed that the intervention prevented loss of muscle strength in the intervention group (Goodpaster et al., 2008). Conversely, previous evidence highlighted inconsistent associations between light PA (LPA) and muscular health outcomes. For example, it was found a positive association between muscle mass and strength only with MVPA (Sanchez-Sanchez et al., 2019), while another study demonstrated that even LPA is positively associated with muscle mass in older adults (Aggio et al., 2016). However, a more recent study on older adults found that engagement in LPA only shows a marginal effect on some of the components related to sarcopenia, without any significant effect on sarcopenia prevalence. From the analysis performed in this study, they noted a reduction in sarcopenia rates with 15 min/day increase in MVPA by reducing SB and LPA respectively (Sanchez-Sanchez et al., 2019). From previous evidence, it has been shown that older adults engaging in greater volume of MVPA have better performances also in both self-reported physical function measures and objective measures as gait speed and Timed Up and Go Test (TUG) (Roberts et al., 2017; Halaweh et al., 2016). Previous randomised trials showed that exercise protocols significantly improved muscle function measured both by gait speed and by the TUG in sarcopenic participants (Liao et al., 2018; Kim et al., 2013). Further supporting these findings, a recent study displayed that older adults accumulating longer duration of MVPA and that those replacing small amounts of SB and LPA with MVPA (such as 10 min), even with interrupted sections, have better performances of physical function (Yasunaga et al., 2017). Additionally, a study based on National Health and Nutrition Examination Survey

(NHANES) data considering a large sample size of older adults showed that objectively measured MVPA is positively associated with self-reported physical function based on activity of daily living scale (Steeves et al., 2019). These observations suggest the presence of a PA intensity threshold under which little benefit is obtained on muscular health outcomes and that even small changes in MVPA duration have a positive effect on sarcopenia incidence in older adults.

BMD increases in response to physical loading and mechanical stress. Thus, evidence supports the role of PA via muscle contraction and gravity (Ng et al., 2021) as protective for BMD during ageing. A recent review on PA and osteoporosis prevention in older adults highlighted the presence of moderate quality evidence that PA has a positive effect on BMD, particularly on lumbar spine BMD (Pinheiro et al., 2020). This finding is further supported by a recent longitudinal study assessing BMD and movement behaviours (Rodriguez-Gomez et al., 2020). This study showed that an increase in MVPA was significantly associated with positive change in BMD at spine and hip level for older adults with no or positive changes in frailty levels (Rodriguez-Gomez et al., 2020). A previous randomised controlled trial involving 35 healthy older men in the UK demonstrated a beneficial effect of balance and function exercise (multidirectional hopping) on BMD (Allison et al., 2013). Similarly, a 1-year randomized controlled exercise intervention trial assessed the effects of two different training programs and their combination on bone health in older women showed that the combination of exercise had positive effect on the BMD of the loaded tibia (Karinkanta et al., 2007). Additionally, a meta-analysis (Qu et al., 2014) showed an inverse association between PA and overall fracture risk, indicating that increased PA levels lead to an increased BMD with a reduced fracture risk in adults. Studies considering different PA intensities, highlighted that MVPA had a consistent positive effect on BMD (Onambele-Pearson et al., 2019), conversely LPA effect did not seem to be relevant and effective on bone health in both genders.

Body composition changes during ageing with an increase of fat mass, which increases susceptibility of older adults to metabolic syndrome and cardiovascular disorders (Jura & Kozak, 2016). Blood pressure, BMI, and waist circumference (WC) are well-established body composition and cardiometabolic health markers (Kim, 2016). Previous evidence highlighted the beneficial role of PA on cardiometabolic health in older adults (Chastin et al., 2015), with studies showing that adults meeting PA guidelines have lower values of WC (Chastin et al., 2015). This study showed that re-allocating 10 minutes of SB to MVPA was associated with a lower WC by 0.001% but if 10 minutes of MVPA is displaced by SB this was associated with a 0.84% higher WC (Chastin et al., 2015). A previous randomised controlled trial on 42 older adults aged 70-89 years old showed that age-associated increase in muscle fat infiltration could be prevented with increased PA (Goodpaster et al., 2008). However, results for older adults are inconsistent and dependent on the PA intensity. Specifically, considering the 24-h time period, the reallocation of time from other behaviours (LPA, SB, or sleep) to MVPA was consistently associated with favourable adiposity outcomes (BMI and waist-to-hip ratio) (Grgic et al., 2018). Although evidence supports the idea that engaging in higher MVPA provides greater protection for cardiometabolic health when compared to LPA (Chastin et al., 2015), a study considering the whole 24-h day found that replacing SB with LPA could have beneficial health effects, contributing toward a more favourable cardiometabolic risk profile.

1.3.2 Sedentary behaviour

From previous evidence, SB displayed detrimental effect on muscular outcomes independently of PA levels. Evidence highlights that prolonged periods of sitting time are associated with reduced muscle strength, muscle mass, and increased risk of sarcopenia in older adults independently from PA (Gianoudis et al., 2015; Reid et al., 2018). Specifically, a 1-h increment in overall daily sitting time in older adults lead to a 33 % increased risk of having sarcopenia (Gianoudis et al., 2015). SB appears to have negative impacts also on physical function in older adults. Indeed, a previous randomised controlled trial showed that an intervention targeting reduced sedentary behaviour improved physical function among older adults over 12 weeks assessed by 400-m walk test and the Short Physical Performance Battery (Barone Gibbs et al., 2017). In different studies objectively measured SB was negatively associated with functional fitness, independent of the time spent in PA (Harvey et al., 2018; Reuter et al., 2020). Older adults who spend more time sedentary tend to perform worse across functional measures as gait speed, ability and dynamic balance (Timed Up and Go test, TUG), with participants performing less than 30min/day of MVPA displaying lower physical function from the Senior Fitness Test battery (Cooper et al., 2015). Additionally, daily breaks in sedentary time in older adults are a strong predictor of lower limb functionality and overall physical capability (Sardinha et al., 2015). Specifically, older adults with higher number of breaks from SB have better scores in fitness tests and muscle quality (Sardinha et al., 2015). These findings suggest that muscular health during ageing is improved by pairing messages to limit sedentary activities with those promoting adequate MVPA engagement.

Previous evidence highlighted a consistent negative association of SB both self-reported and objectively measured with BMD in women, regardless of PA levels (Gobbo et al., 2020). Furthermore, it is known that prolonged sitting is detrimental to bone integrity due to the lack of muscle contraction on bone as well as the absence of ground reaction forces (Kohrt et al., 2004). Previous findings supported this idea as prolonged sedentary bouts were negatively associated with femoral BMD in women (Chastin et al., 2014).

Existing evidence supports the detrimental effect of SB on adiposity and body composition in older adults (Biddle et al., 2010). Specifically, adiposity profiles are worse when individuals spent more time in SB, even with the same amount of time spent in MVPA (Zhu et al., 2020). Previous randomised controlled trials in older adults explored the efficacy of interventions aiming to reduce SB and to improve WC and blood pressure outcomes (Lyons et al., 2017; Roberts et al., 2019; Rosenberg et al., 2020). However, a recent Cochrane systematic review showed that these trials can only provide low certainty evidence (Chastin et al., 2021).Additionally, findings for SB with compositional data analysis (24-h approach) are mixed. For example, in a recent study on the Canadian Health Measure Survey data from adults and older adults (McGregor et al., 2018), the time reallocation of SB relative to other movement behaviours showed no statistically significant associations with adiposity and cardiometabolic indicators. This finding is in contrast to previous compositional studies, particularly with respect to adiposity outcomes. Indeed, a previous study found that time spent in SB has a negative association with cardiometabolic risk outcomes (BMI, waist circumference, and high-density lipoprotein cholesterol) (McGregor et al., 2019). However, the strength of the association depended on the balance of time between MVPA and LPA (McGregor et al., 2019).

1.3.3 Sleep

Consistent associations have been found between sleep duration, sleep quality, and muscle health outcomes. Previous evidence observed hormone imbalances with adverse sleep patterns and sleep disturbances. Different protein synthesis and degradation pathways are mediated by growth hormone, insulin-like growth factor-1, testosterone, cortisol and insulin, which have an effect on muscle metabolism with the ability to increase muscle fibres, strength, and function (Piovezan et al., 2015). Age-related sleep problems potentially interfere by inhibiting anabolic hormone cascades and enhancing catabolic pathways in the skeletal muscle (Piovezan et al., 2015). Indeed, previous randomised controlled trials explored the effect of sleep deprivation on testosterone and cortisol release in young adults of skeletal muscle degradation aggravating the risk of sarcopenia and increased adiposity (Smith et al., 2019; Minkel et al., 2014; van Leeuwen et al., 2018). Previous studies identified a U-shape pattern association between both self-reported and objectively measured sleep duration and sarcopenia incidence in older adults (Buchmann et al., 2016; Chien et al., 2015). Specifically, individuals with short sleep durations (<6 hours per night) and those with long sleep durations (>8 hours per night) displayed lower values of muscle mass and muscle strength compared to those with normal sleep durations (6-8 hours per night), especially in older women (Chien et al., 2015). Moreover, a previous study on European older adults revealed similar results to those above, with significant association between sleep duration and muscle mass (Buchmann et al., 2016). Most studies indicate strong evidence on the association between sleep duration and grip strength; prolonged sleep duration may directly result in decreased muscle strength because of prolonged periods in bed (Chen et al., 2017). Conversely, short sleep duration, through greater sleep fragmentation, and poorer sleep efficiency predict, and might cause a decline of grip strength (Nakakubo et al., 2018). Sleep quality showed consistent negative associations with both muscle mass and muscle strength. Evidence supports the idea that poor sleep quality is independently associated with weaker muscle strength and slower walking speed (as a measure of physical functioning) in older adults (Kim et al., 2015). Additionally, sleep quality components (sleep efficiency, daytime dysfunction) were significantly associated with hand grip strength, and women with poor sleep quality displayed reduced strength (Spira et al., 2012). However, when sarcopenia rates are considered no differences in sex where found, with both men and women with inadequate sleep quality and duration displaying higher prevalence of sarcopenia (Rubio-Arias et al., 2019). Thus, sleep assessment should be expanded to cover dimensions such as sleep quality and sleep disorders to help maintain wellness in older adults.

Patterns of sleep duration appear to share a U-shaped association with bone health (Fu et al., 2011). Specifically, compared with 8 h per night, an hour decrease of sleep duration was associated with 3% increased risk of osteoporosis, and an hour increase of sleep duration was associated with 1% increased risk (Wang et al., 2018). The lowest risk of osteoporosis was present for older adults sleeping between 8 and 9 hours per night (Wang et al., 2018). Therefore, information on sleep duration should be included when considering musculoskeletal health.

Evidence supports the idea that sleep duration and sleep disorders play a role in the morbidity of health conditions in older adults (Crowley, 2011). Specifically, sleep duration is often associated with adiposity and blood pressure markers (Bacaro et al., 2020; Gottlieb et al., 2006). Recent reviews highlighted a U-shaped relationship with adiposity, respectively with an increase in obesity incidence for both short (38%) and long (8%) sleepers than normal sleepers (Tan et al., 2018). However, long sleep duration is consistently associated with negative health outcomes (Chaput et al., 2020). This association could be a direct consequence of altered mechanisms due to long sleeping, but it could be possible that individuals with longer sleeping time experience more disrupted and poorer quality of sleep (Li et al., 2018). Therefore, long sleep can be both a marker of risk for cardiometabolic disorders and a behavioural risk factor that could possibly be modified with public health measures.

1.4. Combined effect of 24-h movement behaviours on health outcomes

Movement behaviours include all activities over a 24-h period across the movement spectrum, on a continuum from no/little movement (sleep, SB) to movement of greater intensities (LPA and MVPA). Importantly, time spent in each movement behaviour is related to the time spent in the other movement behaviours. Indeed, increasing the relative time spent in one behaviour will result in a decrease in another as they are measured in a discrete period of time (24-h). Consequently, recent studies began to investigate the combined effect of movement behaviours on health using isotemporal substitution and compositional analysis techniques (**Table 2**) (Rollo et al., 2020). Isotemporal substitution models estimate the effect of replacing one movement behaviour with another activity behaviour for the same amount of time (Mekary & Ding, 2019). Compositional data analysis is a well-established statistical approach, and it deals with data that represent parts of a finite total, defined as composition (i.e. 24-h day). The absolute values in the composition are transformed into sets of log-ratios, with appropriate transformation data can be analysed with standard statistical techniques and assumptions applying to real space data (Gupta et al., 2018; Dumuid et al., 2018a). However, the majority of the studies took into consideration populations in HICs as United States (McGregor et al., 2019), Canada (McGregor et al., 2018), Australia (Dumuid et al., 2018b), and only three studies from Europe (Rodriguez-

Gomez et al., 2018; Pelclova et al., 2018; Powell et al., 2020); this highlights a lack of evidence from LMICs and European HICs. Therefore, future studies should involve populations from other HICs and diverse socioeconomic settings to establish if the associations previously displayed are still valid.

Table 2. Summary of studies investigating effects of 24-h movement behaviours on health

Health Outcomes	**Authors (year)**	**Age group (age range in years)**	**Association with health outcome (Yes/No)**
Body composition and adiposity (BMI, waist circumference, waist to hip ratio, body composition)	Chastin et al. (2015) Gupta et al. (2019) Kim et al. (2020) Dumuid et al. (2018) Powell et al. (2020) McGregor et al. (2018) Pelclová et al. (2019)	Adults (21-64) Adults Adults/older adults (20-75) Older adults (60-70) Older adults (55-74) Adults/older adults (18-64/65-79) Older women (60+)	Yes
Blood pressure (systolic and diastolic)	Chastin et al. (2015) Gupta et al. (2019) Dumuid et al. (2018) McGregor et al. (2018)	Adults (21-64) Adults Older adults (60-70) Adults/older adults (18-64/65-79)	No consistent findings
Grip strength	McGregor et al. (2018)	Adults/older adults (18-64/65-79)	Yes (adults) No (older adults)
Muscle mass	Gaba et al. (2021)	Older adults (60+)	No
Bone health (BMD, BMC, cortical thickness)	Rodrıguez-Gomez et al. (2018) Moradell et al. (2021)	Older adults (65+) Older adults (65+)	Yes Yes
Aerobic fitness	McGregor et al. (2018)	Adults/older adults (18-64/65-79)	Yes

The most consistent favourable finding is the association of the proportion of time spent in MVPA and health outcomes. For example, a recent study found that the relative distribution of daily time across 24-h movement behaviours is significantly associated with mortality risk (McGregor et al., 2019). Specifically, the most beneficial effect on mortality risk is driven by the proportion of time spent in MVPA relative to the other behaviours. It was also found that the balance of LPA to sleep and SB significantly reduced mortality risk. The findings for 24-h movement behaviours other than MVPA are mixed. Previous evidence reported additional benefits conferred from LPA and sleep duration when reallocated from SB for adiposity and cardiometabolic health (Farrahi et al., 2021). The most consistent associations between 24-h movement behaviours and health outcomes are reported for body composition and adiposity measures. Increases in SB were significantly associated with increases in BMI and fat mass, while LPA displayed beneficial effect on the decrease in BMI and body fat mass in older adults (Powell et al., 2020). Other studies reported an association between higher time spent in MVPA relative to the other behaviours and lower BMI and waist circumference among adults (McGregor et al., 2018). Additionally, positive associations were observed between larger proportions of MVPA time relative to other behaviours and aerobic fitness, as well as between relative time spent in LPA and grip strength among adults. However, no consistent associations were found for older adults and muscle health (grip strength and muscle mass) (McGregor et al., 2018). Conversely, two recent studies found significant combined effects of 24-h movement behaviours on bone health (BMD and bone mineral content) in older adults (Rodriguez-Gomez et al., 2018; Rodriguez-Gomez et al., 2019). Thus, future studies should be directed to the assessment of the association between the composition of 24-h movement behaviours, musculoskeletal outcomes, body composition, and physical functioning as important markers of mobility and functional independence.

1.5. Summary of knowledge gaps and research questions

Osteoporosis, sarcopenia, and obesity are common disorders in older adults and strategies to reduce this risk should be a main focus to maintain quality of life with ageing. Additionally, the deterioration of muscle strength, muscle function and functional mobility leads to impaired ability to engage in physical activities in older adults (Milanovic et al., 2013). Walking is the main component of physical activity in healthy older adults and previous studies reported associations between gait characteristics and physical activity suggesting that gait biomechanical factors might contribute to lack of walking in older adults (Egerton et al., 2017; Elhadi et al., 2017). Specifically, older adults with slower gait speed, shorter step length, shorter step time, shorter swing time were less active (Egerton et al., 2017). However, only a small number of studies have examined the association between temporal gait parameters and muscle activities across the lifespan. Therefore, it is important to identify gait characteristics of older adults at risk of future decline in PA. One of the main issues is a lack of data on changes in functional mobility, specifically walking behaviour, in middle-aged and older adults measured in a laboratory-based condition. However, limitations on the impact of these measures on the whole 24-h day are evident, as they are providing information on a restricted time period and in a laboratory environment (Takayanagi et al., 2019). Therefore, I aim to expand the research into a real-world approach by considering effect of the whole 24-h movement behaviours spectrum on musculoskeletal health, adiposity, and physical functioning in older adults as a particular vulnerable group to decline in general health. There is no specific evidence available regarding the most appropriate intensity and volume of aerobic physical activity to best provide protection against bone and muscle loss during ageing. Indeed, PA recommendations for bone and muscle health should be distinguished from those for body composition and cardiovascular health.

According to the evidence presented, differences in PA domains across different socioeconomic settings should be taken into account. Differences in 24-h movement behaviours between socioeconomic settings may suggest a different reallocation of specific PA behaviours in the two settings, representing an important target to improve research translation of behaviour into context-specific population health. To date, no studies have explicitly explored the relationship of 24-h movement behaviours to muscle and bone integrity, adiposity and physical functioning in older adults of similar age living in diverse communities in South Africa (LMIC) and Scotland (HIC). Additionally, there is limited research reporting on changes in walking in middle-aged adults and objectively measured sleep in South African and Scottish older adults. Accordingly, the aims of this thesis are:

- To determine changes in usual walking on flat and uneven surfaces across the adult life span – Chapter 2.
- To assess and examine differences across Scottish and South African communities and associations of objectively measured 24-h movement behaviours with musculoskeletal outcomes (muscle strength, muscle mass, physical performance, and bone mineral density) – Chapter 3 and 4.
- To explore associations of objectively measured 24-h movement behaviours with body composition and adiposity outcomes (BMI, fat mass, waist circumference, and blood pressure) in Scottish and South African communities – Chapter 5. Additionally, our aim was to explore the role of self-reported sleep quality on musculoskeletal health, adiposity, and physical functioning across South African and Scottish communities – Chapter 4 and 5.

The original thesis plan also involved the recruitment of a subsample of 20 participants (female adults aged 60-85 years living in Scotland and South Africa) for a lab-based data collection on neuromuscular aspects. Specifically, I was going to do a motor unit assessment through intramuscular electromyography (iEMG) and surface electromyography (sEMG) on a thigh muscle (Vastus Lateralis) and shin muscle (Tibialis Anterior) of the same leg. Neural control of skeletal muscle is a key contributor to the loss of muscle mass and physical function in older adults and these lower limb muscles are directly involved in gait phases. The aim of this third study was to assess the loss of skeletal muscle function with ageing and associations of muscle strength (force steadiness and maximum voluntary contractions of lower limb muscles) with functional mobility. With this study, I was going to obtain data on mechanisms underlying sarcopenia with possible implications in developing novel interventions to ameliorate age related decline in motor performance, mobility, and physical activity. I was unable to start the subsample data collection as planned. From April 2020, my supervisory team and I had to plan different analysis to provide a new frame to my PhD thesis. Consequently, we had to further discuss and adapt the thesis theme.

The overall hypotheses of the thesis are:

1. Temporal parameters and muscle activity of usual walking will differ across age groups and surface conditions. Specifically, older adults will show a more cautious walking and greater walking effort, defined as higher muscle activation, compared to young adults.
2. Movement behaviours, particularly PA, will have a similar volume but will differ in intensity in older adults in socioeconomic settings, with Scottish community displaying higher intensities of PA related to a greater engagement in leisure MVPA. These differences will have an influence on musculoskeletal, adiposity, and physical functioning outcomes.

Chapter 2: Laboratory-based gait analysis of age-related changes in walking on different surface conditions

2.1 Introduction

In Chapter 1, the concept of walking as a main component of real-life mobility and physical activity (PA) was described. Specifically, evidence regarding assessment of walking quality and its role as a marker of physical function and health status across the adult life span was reviewed. As mentioned in the previous Chapter, assessment of gait parameters and their variability provides information on determinants of safe and efficient walking, along with age-related changes in walking effort leading to gait disorders (Salzman, 2010). The underlying factors contributing to changes in walking performance during ageing are associated with changes in musculoskeletal health (Schmitz et al., 2009) and motor control (Godde & Voelcker-Rehage, 2017). Impaired mobility and reduced walking performance are closely associated with increased mortality among older adults (Studenski et al., 2011). Therefore, age-related gait adaptations in young, middle, and older adults are important, and will be assessed in this Chapter.

Studying walking in physically challenging situations (such as walking on uneven surfaces) can allow for increased sensitivity of muscular and motor pattern age-related changes identification (Kovacs, 2005). Previous evidence reported decreased gait speed, increase in temporal parameters variability, and decrease in step length in older adults walking on uneven surfaces (Menant et al., 2009; Da Silva Costa et al., 2020). When muscle activation is considered during walking on flat surfaces, older adults display a redistribution of muscular dynamics (Schmitz et al., 2009; Vernooij et al., 2016). Specifically, in a previous study, older adults displayed greater coactivation of muscles at ankle and knee during mid-stance and a reduced dependence on soleus muscle activation to push off, compared to young adults (Schmitz et al., 2009; Vernooij et al., 2016). Additionally, muscle activation dynamics provide information on how individuals respond to perturbations and maintain stability during walking (Kang & Dingwell, 2009). Therefore, it is important to understand the impact of age-related changes of muscular forces over multiple strides on walking ability potentially leading to gait disorders. Gait disorders in older adults are a risk factor for falls and are associated with increased mortality and loss of independence (Hausdorff et al., 2001; White et al., 2013). Falls are an important public health issue and around 50% of falls in healthy older adults are caused by uneven surfaces (Li et al., 2006). A previous study reviewing evidence from Scottish national datasets has identified the burden of falls on health and social care services as being approximately 85,000 episodes each year, followed by high number of hospitalisations. Among hospitalised older adults over 20% of them are unable to return home, with associated costs estimated at over £470 million (Craig et al., 2013). Previous studies also found an association between falls, fear of falling, and functional activity restriction. Indeed, older adults who experienced a fall had increased risk of fear of falling compared with individuals who did not fall, leading to reductions in PA (LeBouthillier et al., 2013). This highlights the need to investigate walking performance on different surfaces to gain insights into how individuals adapt their gait with advancing age. Additionally, assessing changes in muscle activations in the lower limb during walking could provide information on biomechanical and neuromuscular adaptations during ageing (McGibbon, 2003). However, most of previous studies were performed on treadmills or at selected gait speed (Li et al., 2012; Terrier & Reynard, 2015), which may not adequately replicate real-world walking conditions and a recent review highlighted a dearth of evidence on walking performance in middle-aged adults (Herssens et al., 2018). The current study expands on previous results by investigating age-related differences in muscle activity and temporal parameters of gait on different surface conditions (flat vs uneven). Indeed, assessment of the neuromuscular challenge encountered by lower limb muscles in healthy adults and older adults can provide baseline information for future strength training interventions.

Irregular walking surfaces present a challenge to the motor and neuromuscular systems and can increase sensitivity in identifying age-related changes during gait (Kovacs, 2005). Better understanding of strategies adopted to stabilise walking and changes in lower-limb motor control during gait could have implication for future fall prevention strategies. Additionally, as mentioned above, older adults have higher muscle activation during walking compared to young adults on flat surfaces, and this is closely associated with an increase in walking effort and muscular demand (LaRoche et al., 2018). Nevertheless, the most common reported physical activity (PA) in older adults are ambulatory activities such as brisk walking and jogging (Szanton et al. 2015), which stress the neuromuscular system, potentially leading to an increase in neural cost and effort needed to walk. Indeed, a previous study reported an association between physiological indicators of walking effort (increased vastus lateralis activation) and objective measures of daily PA (LaRoche et al., 2018). Specifically, older adults with high neuromuscular responses displayed a low daily stepping time and reduced sit-to-stand transitions per day (LaRoche et al., 2018).

Therefore, it is important to investigate increases in walking costs due to high muscular activations in order to reduce effort of ambulatory activities in older adults. Findings could inform future exercise programs aiming to improve neuromuscular capacity and support PA engagement in older adults.

The aims of this Chapter were to describe an experiment conducted to compare gait temporal parameters and muscle activation over flat and uneven surfaces, and to evaluate the differences between young, middle-aged, and older adults over these surface conditions. Based on evidence mentioned above I hypothesized that older adults would display specific age adaptations in temporal gait parameters, consistent with a conservative and careful gait pattern, with longer double support phase and shorter swing phase compared to younger adults. Additionally, I hypothesised that older adults would display greater activation of knee and ankle muscles during walking, compared to young adults.

2.2 Methods

2.2.1 Participants and approvals

Eighty-three healthy adults aged from 18 years old to 82 years old provided informed consent in this experiment. Participants were recruited from local communities around Stirling (Scotland), University of Stirling (students and staff members), partner organisations and contacts including churches, fitness classes for older adults, and snowballing through personal contacts. All participants were reportedly physically active (defined in this context as exercising at least once a week), able to walk without aids, had no recent injury or surgery in the lower limbs and were free from medication, drugs, and alcohol use. Individuals were split in three groups based on their age: young adults 18-39 years, middle-aged adults 40-59 years, older adults 60+. The study was performed according to the Declaration of Helsinki and later amendments. This experimental study was approved by the Stirling University research ethics committee (NHS, Invasive or Clinical Research Panel).

2.2.2 Study design

For this observational cross-sectional study, participants joined a single session experiment. Upon arrival, anthropometric data were collected. Body mass was measured to the nearest 0.1 kg using a digital weighing scale (Soehnle Connect, Soehnle-Waagen GmbH and Co.KG, Murrhardt, Germany) in light-weight clothing without shoes and height was assessed to the nearest 0.1 cm using a portable stadiometer (Seca 213, Birmingham, UK). For both measurements, the average value was considered. Body mass index was computed as body mass (kg)/height (m^2) (World Health Organisation, 1998). Participants answered a series of questions on demographic data (education in years, sex, and age) and they were asked a question on PA habits: *"How many times per week do you exercise for a minimum of 30 minutes a session?"*. A range of 4 potential answers were provided: exercise 4 or more times per week, exercise 2 to 3 times per week, recreational sport once a week, recreational sport occasionally or complete lack of exercise. Pressure-sensing insoles (Pedar-X ®) were fitted into individual's own shoes in order to record walking temporal features. Data were collected at 50 Hz. The Pedar-X system is an in-shoe dynamic pressure distribution measuring system with a high reliability to detect changes during walking (Ramanathan et al., 2010).

Gait and muscular parameters were measured during a series of continuous 4-minute walking trials on a flat and uneven surface, and participants were instructed to walk at their usual pace, following a linear path (10 meters long). Each participant performed a total of four trials with a 1-minute rest in between, two trials on a flat surface and two trials on an uneven surface. Gait speed on the flat surface was recorded on the 10m carpet and time was measured manually for a 6m distance (from 2m to 8m) to avoid influences of acceleration and deceleration (Duncan et al., 2017). Participants were instructed to walk at their usual pace, and the average value across flat trials is reported. The order for trial presentation was randomized across participants. The randomization blocks were created through Sealed Envelope™. Upon reaching the end of the path, participants turned 180° and continued walking for a total of 4 minutes to complete at least 100 strides (Riva et al., 2014). Changes of direction were kept in the temporal gait parameters as part of real-life walking (they were excluded for gait speed calculation and electromyography analysis). To better identify changes of direction two pressure sensors were located at both ends of the carpet. At the beginning of each walking trial, participants were asked to maintain the upright position on one foot (without indicating a preference for a specific leg) and count for 10 seconds before resuming their walking to easily identify the first step on the carpet during the analysis. For the uneven surface trials, 10 wooden blocks were placed under the carpet with a randomized order. The blocks were numbered to assess possible usage and damages. Before the beginning of the trial, participants were asked to perform a normalization task based on daily life activities (Ghazwan et al., 2017) to normalise muscle activation recordings across participants. Participants were seated on a chair, when the experimenter gave the start, they stood up from the chair, walked for 2 meters and climbed 3 steps of different height (first and last one was 10cm height and the middle step was 20 cm height), walked again for 2 meters, turn back, and repeated the same path. The task ended when the participant sat back on the chair (**Figure 3**).

Figure 2. Normalisation task setting based on daily life activities for sEMG comparison (Ghazwan et al., 2017).

2.2.3 Muscle activity

Surface electromyography (sEMG) data were collected using wireless sensors on the right lower limb and sampled at 2000 Hz with Acqknowledge software (version 3.9.1, BIOPAC Systems Inc, Goleta US). Prior to electrode positioning, skin was shaved and cleansed with an alcohol swab according to SENIAM recommendations (Stegeman & Hermens, 2007). The sEMG was performed with a pair of AgCl disc electrodes of 36x40mm placed on the skin over 6 muscles of the right lower limb in the direction of the muscle fibres: biceps femoris (BF), quadriceps vastus lateralis (VL) and medialis (VM), lateral gastrocnemius (GL), medial head gastrocnemius (GM) and tibialis anterior (TA) (**Figure 4**), according to the Anatomical Guide for the Electromyographer (Murray, 1995). These muscles were selected due to their fundamental roles in mobility, and their weakness has been associated with postural instability and increase risk of falls in older adults (Horlings et al., 2008). The interelectrode (centre-to-centre) distance was 20mm for each muscle. Reference electrodes were positioned over the knee and the ankle joints.

Figure 3. sEMG placement on the right leg (Murray, 1995). Front and back.

2.2.4 Gait temporal parameters definition

Gait cycle is defined as subsequent heel contacts of the same limb (Kharb et al., 2011). Stride time is defined as the time between the heel strikes of two consecutive heel contacts of the same foot. Swing phase is initiated with toe off and ends with heel strike of the same foot, expressed as time (sec) and as percentage of 1 gait cycle (%GC). Stance phase starts with the heel contact and ends with the toe off from the same foot with the load of the body being held on the leg involved in this phase, expressed as time (sec) and percentage of a gait cycle (%GC). Double support phase is considered when both feet are in contact with the ground simultaneously, expressed only as percentage of a gait cycle (%GC). **Figure 5** represents a summary of main gait phases considering the right leg.

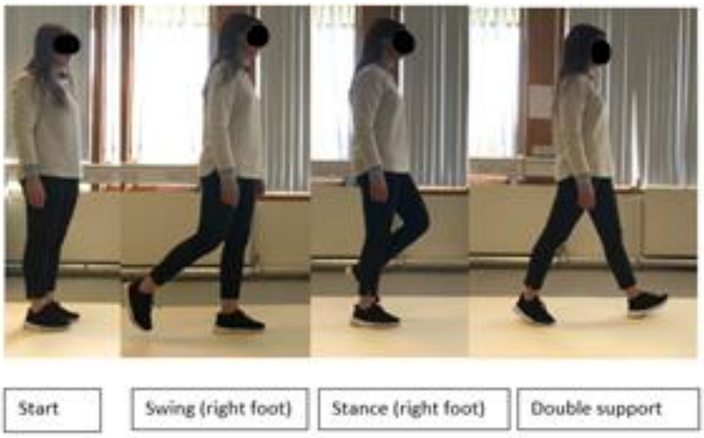


Figure 4. Summary of gait phases on the right leg.

Gait variability, defined as the variations that occur across multiple strides (Hausdorff, 2005), was also measured. Variability was measured with coefficient of variation (CV). The CV values were calculated using the formula: $(\sigma / \mu)*100$; where σ is the standard deviation, and μ is the mean of the sample (Hausdorff, 2005). A gait analysis software program (Pedar Online) was used to identify the first and second heel contact events during usual speed walking on both surface conditions, and these heel contact events were used to locate the gait cycle with respect to the sEMG signal. A total of 20 gait cycles were identified for each trial and included in the analysis.

2.2.5 Muscle activity analysis

The sEMG signals were captured at 2000Hz and bandpass filtered (passband 20–300Hz), notch-filtered at 60Hz using a Butterworth filter. Then, signals were normalised to the peak amplitude during the normalization task to allow the comparison between subjects. Normalised signals were then rectified and filtered. In order to synchronise muscles activity with temporal gait parameters, we down sampled the sEMG signal to 50Hz. The rectified sEMG cycles were time-normalized to 101 points from 0 to 100. To establish muscle activation during different stages of walking we divided the whole gait cycle in different phases according to previous literature (Bailey et al., 2018). The phases that were explored were: loading (0–10%), mid-stance (10–30%), terminal stance (30–60%), initial swing (60–73%), mid-swing (73–87%), and terminal swing (87–100%). For each of the six muscles recorded, root mean square (RMS) was extracted from each phase of the gait cycle (0–100%), to quantify the magnitude of muscle activation.

2.2.6 Statistics

Statistical analysis was performed using SPSS IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA). Descriptive statistics for continuous variables were expressed as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Univariate analyses were performed for demographic variables (age, sex, education, dominant leg, body mass, height, BMI, PA habits, and gait speed) to investigate where significant differences existed. Normality of the variables was assessed through the Shapiro-Wilk Test and visual assessment through the QQ plot. To test hypotheses examining the effects of age and surface on gait temporal parameters and muscle, a 2 ×2 mixed design Analysis of Variance (ANOVA) was performed using age (young/middle/older adults) as a between-subject factor and surface (flat/uneven) as a within-subject factor. An age (3) × surface (2) interaction was included to test the hypothesis that the effects of surface differed in older adults. Partial Eta-Squared (η^2) was used to quantify effect sizes. Separate analyses were performed for each dependent variable (temporal parameters and muscle activation). In the case of a significant interaction, paired post-hoc tests with Bonferroni corrections were used to compare differences in groups by condition (young/flat vs young/uneven, middle/flat vs middle/uneven, and old/flat vs old/uneven). A p value of .05 or less was considered as statistically significant.

2.3. Results

2.3.1 Participants characteristics

Participant characteristics are presented in **Table 3**. No significant differences were present in demographic variables across the three age groups. Based on self-reported PA information, adults aged 18-39 years were the least physically active group. Conversely, older adults (participants aged 60+) reported the highest number of exercise sessions during the week. No significant differences were found across the age groups for gait speed.

Table 3. Descriptive variables

	18-39y young adults (n=31)	40-59y middle-aged adults (n=17)	60+y older adults (n=35)
Age (years)	**27 (22-32)**	**48 (43-55)**	**69 (64-74)***
Sex (n, %), Male	14 (46)	4 (23)	14 (47)
Education (years)	17 ±3	18 ±5	18 ±3
Dominant leg (n, %), left	3 (10)	3 (18)	1 (3)
Body mass (kg)	71 ±15	71 ±19	74 ±14
Height (cm)	170 ±11	167 ±12	168 ±9
BMI (kg/m^2)	24 ±4	25 ±4	27 ±5
Self-reported PA (n, %)			
Exercise 4 or more	**13 (42)**	**10 (59)**	**22 (63)***
Exercise 2-3 times per week	**8 (26)**	**5 (29)**	**12 (34)**
Recreational sport once a week	**3 (10)**	**1 (6)**	**0**
Recreational sport occasionally/lack of exercise	**7 (22)**	**1 (6)**	**1 (3)**
Gait speed (m/s)	1.06 (0.11)	1.03 (0.07)	1.05 (0.11)

All normally distributed and skewed data are reported as mean ± SD and median (IQR, 25-75th percentile), respectively. Abbreviations: BMI, body mass index, PA, physical activity. P values represent a significant difference between groups. Parametric and non-parametric independent tests were conducted on normally distributed and skewed data, respectively. Chi-square was used *to determine differences in frequency of each variable between age groups. Statistically significant results (*, p < 0.05) are highlighted in bold.*

2.3.2 Spatiotemporal gait parameters

Complete F statistics results from the two-way mixed ANOVA are reported in Appendix 1. In the following subsections, a summary of the main effects and interactions, along with post-hoc tests results are presented.

2.3.2.1 Stride, stance, and swing time

Results for stride, stance, and swing time in seconds are presented in **Table 4**. A significant surface main effect was observed for stride time, defined as the duration of a complete gait cycle (subsequent heel contacts of the same foot). Specifically, the uneven surface prompted longer stride time duration compared to the flat surface, regardless of age. Stance time (time during which the foot is in contact with the ground) had a significant surface main effect, with each age groups displaying longer stance duration during uneven walking compared to the flat surface. A significant age x surface interaction effect was found for swing time, defined as the time during which the foot is in the air. Specifically, in young ($t(30)=6.92$, $p<0.01$) and older adults ($t(34)=3.11$, $p<0.01$) the uneven surface prompted significantly longer swing time compared to walking on the flat surface. Conversely, no significant differences were observed for middle-aged adults ($t(16)=0.96$, $p=0.35$).

Table 4. Temporal gait parameters compared between age groups across surface conditions

Variables	Surface condition	18-39y young adults (n=31)	40-59y middle-aged adults (n=17)	60+y older adults (n=35)	Effect
Stride time (s)	Flat	1.29 (0.15)	1.30 (0.25)	1.20 (0.16)	b
	Uneven	1.37 (0.16)	1.42 (0.48)	1.28 (0.18)	
Stance time (s)	Flat	0.79 (0.08)	0.77 (0.08)	0.77 (0.15)	b
	Uneven	0.84 (0.10)	0.84 (0.15)	0.84 (0.22)	
Swing time (s)	Flat	0.49 (0.05)	0.46 (0.06)	0.43 (0.07)	a, b, c
	Uneven	0.53 (0.05)	0.48 (0.09)	0.46 (0.09)	

All variables are expressed as mean (standard deviation). Abbreviations: S, seconds.
[a] Significant age group effect (p < 0.05).
[b] Significant surface condition effect (p < 0.05).
[c] Significant age x surface condition effect (p < 0.05).

2.3.2.2 Double support, stance, and swing phases as function of gait cycle

Results for gait phases (double support, stance, and swing) expressed as percentage of the GC are presented in **Table 5**. Events of a gait cycle occur in similar sequences and are independent of time. For this reason, the gait cycle is also expressed in terms of percentage along with information on the time elapsed. A significant surface x age interaction was found for double support phase, with the uneven surface prompting longer time while both feet are in contact with the ground. Specifically, middle-aged adults displayed significantly longer double support phase ($t(15)=3.10$, $p<0.05$). Conversely, no significant differences were found for young ($t(29)=1.24$, $p=0.23$) and older adults ($t(34)=1.64$, $p=0.11$) for flat vs uneven condition. No significant interaction and main effects were found for stance and swing phases.

Table 5. Temporal gait parameters compared between age groups across surface conditions

Variables	Surface condition	18-39y young adults (n=31)	40-59y middle-aged adults (n=17)	60+y older adults (n=35)	Effect
Double support (%GC)	Flat	10.7 (1.9)	11.8 (3.2)	13.1 (5.6)	a, b, c
	Uneven	11.5 (3.3)	15.3 (6.2)	14.1 (4.3)	
Stance (%GC)	Flat	61.3 (2.4)	62.9 (4.4)	63.2 (4.7)	n.s.
	Uneven	61.2 (2.8)	63.2 (5.9)	63.5 (5.1)	
Swing (%GC)	Flat	38.2 (2.4)	36.6 (4.5)	36.3 (4.7)	n.s.
	Uneven	38.3 (2.9)	35.5 (5.1)	36.0 (5.2)	

All variables are expressed as mean (standard deviation). Abbreviations: GC, gait cycle.
[a] *Significant age group effect ($p < 0.05$).*
[b] *Significant surface condition effect ($p < 0.05$).*
[c] *Significant age x surface condition effect ($p < 0.05$).*
[n.s.] *non-significant*

2.3.2.3 Gait phases variability

Results for coefficient of variations for each gait phase and stride time are presented in **Table 6**. Gait variability (also defined as stride-to-stride fluctuations) refers to the fluctuation in the value of a gait measure from one stride to the next. A significant main effect of surface was observed for double support, stance, and swing phase variability. Specifically, the uneven surface led to a more irregular gait pattern than walking on a flat surface, regardless of age. A significant surface x age interaction was found for stride time variability. Specifically, young adults significantly displayed a more irregular walking pattern on the uneven surface compared to the flat one ($t(29)=2.04$, $p<0.05$). No significant differences between flat vs uneven condition were found in middle-aged ($t(15)=1.53$, $p=0.15$) and older adults ($t(34)=0.95$, $p=0.35$).

Table 6. Temporal gait parameters compared between age groups across surface conditions					
Variables	Surface condition	18-39y young adults (n=31)	40-59y middle-aged adults (n=17)	60+y older adults (n=35)	Effect
CV double support phase (%)	Flat	16.16 (11.93)	18.84 (18.55)	20.84 (19.16)	b
	Uneven	29.62 (19.02)	37.57 (27.30)	29.90 (24.87)	
CV stance phase (%)	Flat	3.5 (3.75)	4.90 (5.10)	5.47 (5.99)	b
	Uneven	6.77 (5.61)	10.37 (10.21)	7.16 (6.06)	
CV swing phase (%)	Flat	5.81 (6.75)	11.56 (20.78)	10.34 (13.67)	b
	Uneven	12.43 (15.16)	21.51 (24.01)	16.29 (21.90)	
CV stride time (%)	Flat	4.92 (4.84)	6.13 (6.38)	10.21 (14.97)	b, c
	Uneven	8.74 (10.39)	30.33 (63.53)	13.27 (19.51)	

All variables are expressed as mean (standard deviation). Abbreviations: GC, gait cycle. CV, coefficient of variation.
[a] Significant age group effect ($p < 0.05$).
[b] Significant surface condition effect ($p < 0.05$).
[c] Significant age x surface condition effect ($p < 0.05$).

2.3.3 Muscle activation

Complete F statistics results from the two-way mixed ANOVA are reported in Appendix 2. In the following subsections, a summary of the main effects and interactions, along with post-hoc tests results are presented according to the 6 gait phases mentioned above (2.5). The results of the two-way mixed ANOVA showed that there were significant main age effects for GM during the loading phase, for VL during mid stance phase, and for VM during the whole stance phase and initial swing phase.

2.3.3.1 Loading

Post-hoc tests showed that older adults had greater GM activation during this phase compared to young ($t(53)=2.35$, $p<0.05$) and middle-aged ($t(49)=2.35$, $p<0.05$) adults (**Figure 6**). No significant differences were found between young and middle-aged older adults ($t(52)=0.09$, $p=0.93$). No significant age x surface interaction and surface main effect were found.

2.3.3.2 Mid stance

Follow up tests showed that older adults displayed a significant greater activation of VM (**Figure 7**) compared to young adults ($t(53)=4.23$, $p<0.01$) and middle-aged adults ($t(49)=2.42$, $p<0.05$). No significant differences were found between young and middle-aged adults ($t(52)=1.63$, $p=0.11$). Additionally, older adults displayed a significant higher VL activity during this phase (**Figure 8**) compared to young ($t(53)=2.72$, $p<0.01$) and middle-aged adults ($t(49)=2.09$, $p<0.05$). No significant differences were found between young and middle-aged adults ($t(52)=0.75$, $p=0.46$). No significant age x surface interaction and surface main effect were found.

2.3.3.3 Terminal stance

Post-hoc tests displayed that older adults showed a greater VM activation (**Figure 7**) during this gait phase compared to young adult group ($t(53)=4.24$, $p<0.01$) and middle-aged adults ($t(49)=2.68$, $p<0.05$). No significant differences were found between young and middle-aged adults ($t(52)=1.46$, $p=0.15$). No significant age x surface interaction and surface main effect were found.

2.3.3.4 Initial swing

Significant greater VM activation, as in the previous phase, was found in older adults (**Figure 7**) compared young adults ($t(53)=2.58$, $p<0.05$) and middle-aged group ($t(49)=2.30$, $p<0.05$). No significant differences were found between young and middle-aged adults ($t(52)=0.25$, $p=0.80$). No significant age x surface interaction and surface main effect were found.

2.3.3.5 Mid swing and terminal swing

No significant differences were found across age groups and surface conditions in these gait phases.

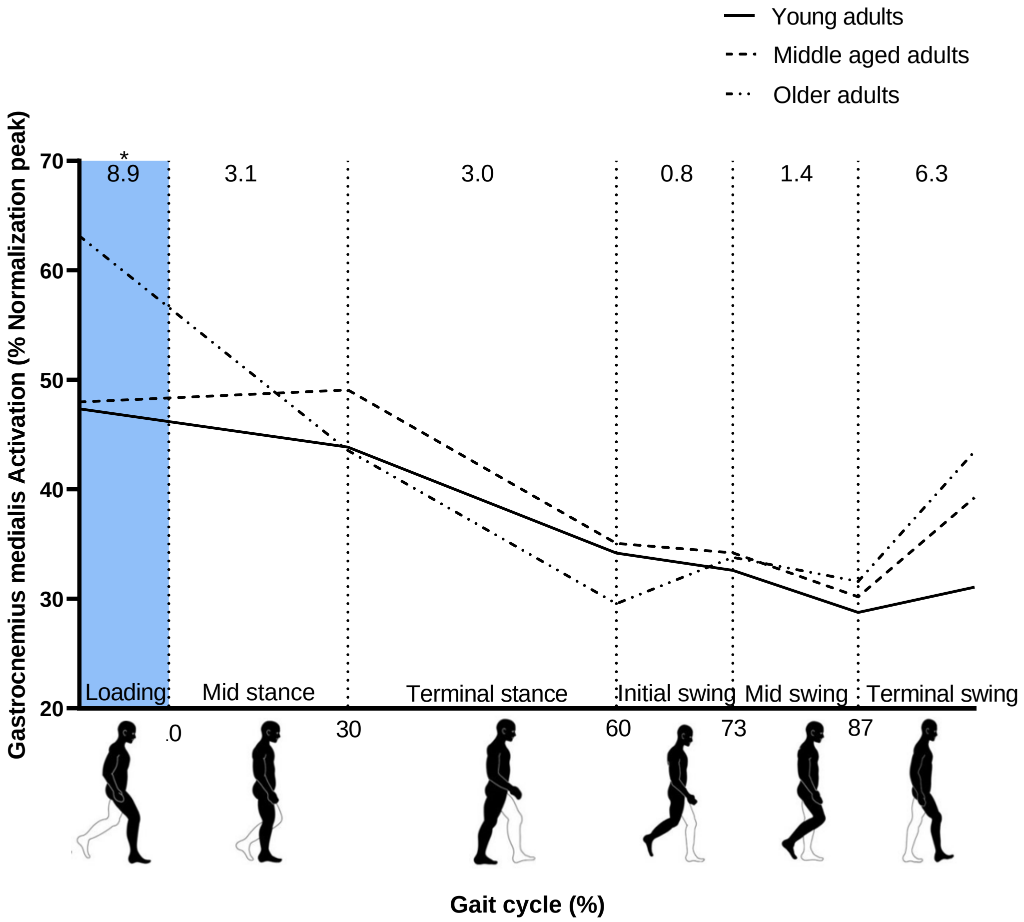


Figure 6. Gastrocnemius Medialis activation during the gait cycle on flat surfaces. To visualize age effects, mean curves were calculated for adults aged 18-39 years (N=31), 40–59 years (N=17), and 60+ years (N=35). Vertical dashed lines identify specific gait phases. Significant age effects p<0.05 (*) on activation amplitude are shown with standard deviations.

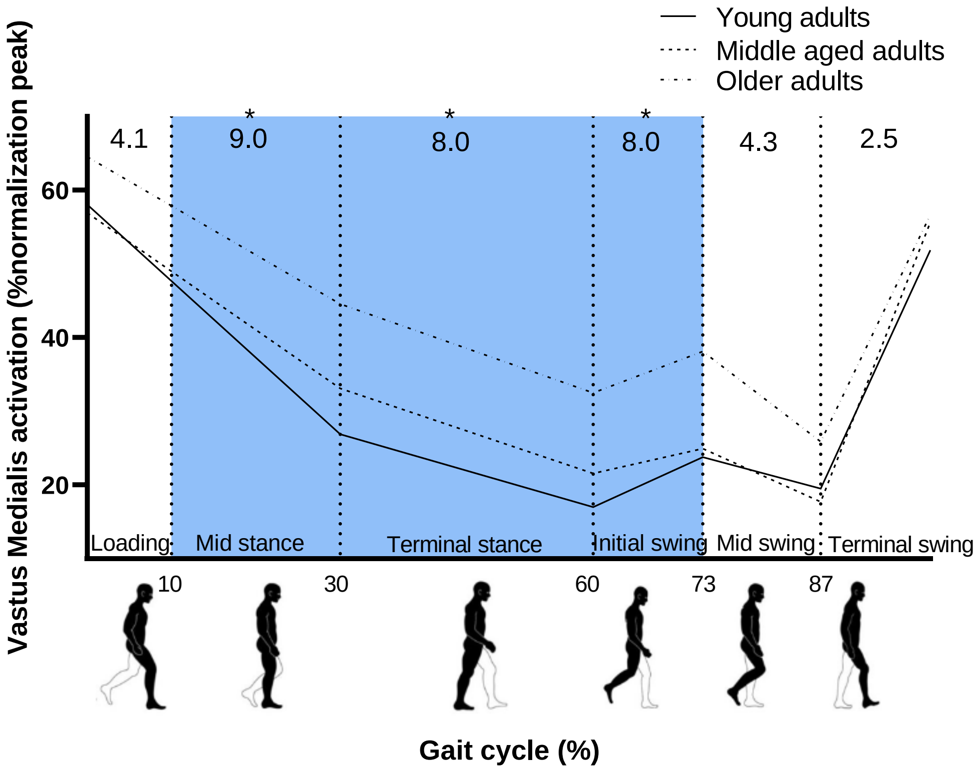


Figure 7. Vastus Medialis activation during the gait cycle on flat surfaces. To visualize age effects, mean curves were calculated for adults aged 18-39 years (N=31), 40–59 years (N=17), and 60+ (N=35). Vertical dashed lines identify specific gait phases. Significant age effects p<0.05 (*) on activation amplitude are shown with standard deviations.

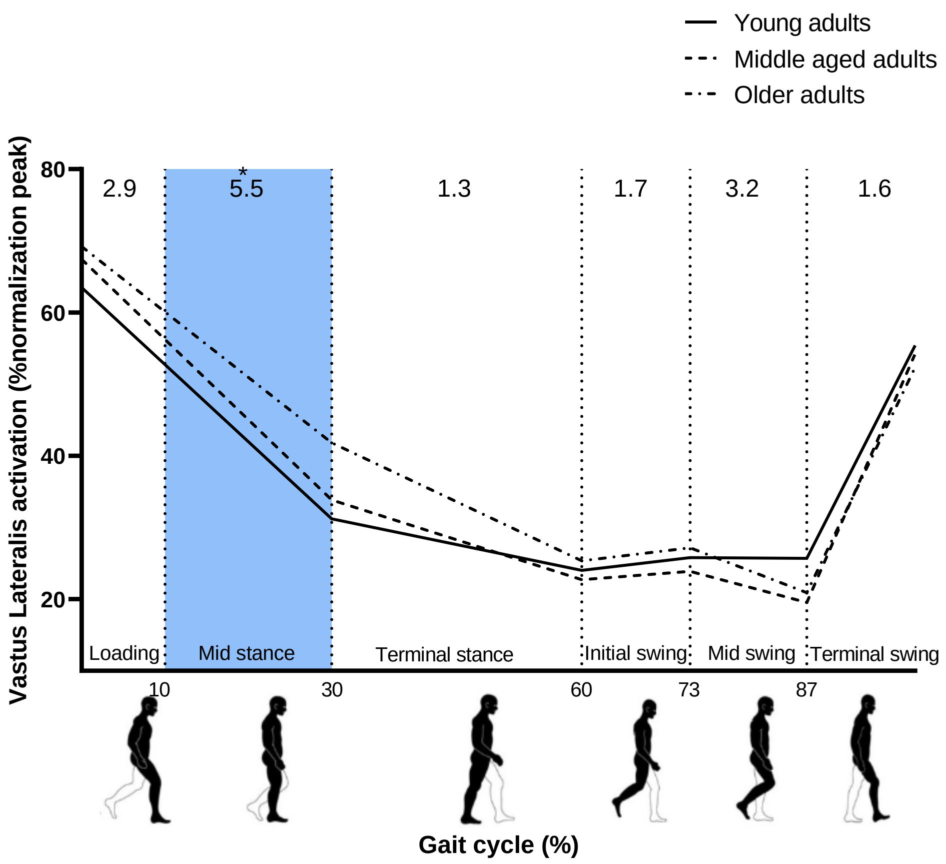


Figure 8. Vastus Lateralis activation during the gait cycle on flat surfaces. To visualize age effects, mean curves were calculated for adults aged 18-39 years (N=31), 40–59 years (N=17), and 60+ (N=35). Vertical dashed lines identify specific gait phases. Significant age effects p<0.05 (*) on activation amplitude are shown with standard deviations.

2.4 Discussion

In this experiment, older adults displayed a more cautious walking on a flat and an uneven surface than the younger participants, as evidenced by a longer double support phase and a shorter swing phase. These age-related changes are considered an approach to increase stability during gait by reducing the amount of time spent balancing on one leg (Maki, 1997) and to counterbalance for decline in lower limbs muscle strength (Aboutorabi et al., 2016). Increased muscle activity was also found in older adults, regardless of surface conditions, at plantar flexor level during loading phase and at knee extensor level during both stance (mid and terminal) and initial swing phase. This supports the idea of an increased muscular demand in older adults during walking, when compared to younger participants. These findings confirm the presence of a more cautious approach to walking in older adults and a greater reliance on knee joint during walking to gain more stability. However, when considering the variability of temporal gait parameters, considered a potential predictor of falls (Hausdorff et al., 2001), we found a surface effect regardless of age. This finding suggests that uneven surfaces negatively impact upon walking and could represent a risk for falls irrespective of age.

Our findings of longer double support and shorter swing phase in older adults are consistent with previous literature (Herssens et al., 2018). These age-related changes in temporal walking patterns have generally been interpreted as indicating the adoption of a more conservative, or less destabilising gait approach (Rosengren et al., 1998), suggesting that older people may compensate for reduced physical functionality and muscle strength by being more cautious (Herman et al., 2005) than their younger counterparts. However, these differences were more pronounced on the uneven surface, indicating that older individuals may have perceived this condition as a greater threat to their stability, and subsequently adopted an even more conservative gait pattern than when walking on the flat surface (Dixon et al., 2018; Marigold & Patla, 2008). Additionally, in previous studies a prolonged double support phase was found to be associated with fear of falling (FOF) (Makino et al., 2017). FOF prevalence is estimated at >20% among community-dwelling older adults (Evitt & Quigley, 2004) and consistently associated with changes in gait temporal and spatial parameters regardless of fall history (Evitt & Quigley, 2004). Thus, future studies should also include psychological factors such as FOF in the assessment of age-related changes in walking.

Our findings on muscle activity highlighted a greater activation of plantar flexor and knee extensors in older adults. Similarly, a previous study (Bailey et al., 2019) found higher GL activation during loading phase. Additionally, older adults in this previous study displayed lower TA and rectus femoris activation during the last phases of the gait cycle. Another study from Schmitz et al. (2009) identified age-related differences in muscle activation only in loading and mid stance phases with an increased gastrocnemius activity. Similarly, in our study, older adults displayed greater VL activity during mid stance phase and VM during the whole stance and initial swing phases. Observed muscle activations were not always in agreement with previous work, potentially due to differences in protocols, surfaces, and populations. However, a greater plantar flexor activation (GL and GM) is common in both cited studies, our findings further support evidence on age-related changes in muscle activity during walking. Additionally, our finding of greater thigh muscle activity (VL and VM) during the stance phase supports the functional distal-to-proximal shift in power production observed during walking in older adults with changes in the relative contribution of the individual muscle groups to the total output of the limb (Schloemer et al., 2017). Higher muscle activity has been associated with a greater effort and muscular demand during walking (Hortobagyi et al., 2011) and with reduced daily stepping time and sit-to-stand transitions per day in older adults (LaRoche et al., 2018). Consequently, these findings could inform future exercise programs aiming to reduce walking effort and potentially support PA engagement in older adults.

There was no effect of age category on gait speed which could be due to high PA levels reported by the older participants on the day of testing, further supporting the presence of a potential association between PA and mobility (Buchner et al., 1996). Indeed, previous evidence has indicated a small effect of age on walking speed and gait mechanics in a population of highly active older walkers (Boyer et al., 2012). Gait changes, in particular reduced gait speed (Studenski et al., 2009), are important determinants of functional independence and mobility conditions during ageing. Walking activities are often the primary mode of physical activity and exercise in older adults (Szanton et al., 2015). Walking has been associated with beneficial effects on gross functional mobility deficits in older adults (Brach & VanSwearingen, 2013). Thus, high levels of PA could contribute to reduced ageing effects on gait. Age-related changes are still present in our sample of high-functioning older adults, suggesting age effect could not be eliminated and that changes in global motor function and ambulatory mechanics with ageing may not be prevented or fully reversed through PA. Additionally, age-related differences reported in our sample are likely to be even more pronounced in people who are less physically active or inactive, especially older adults. The finding of changes in walking behaviour in high-functioning older adults reinforces the need to increase older people to be physically active so that the rate of decline is less pronounced. Older adults who are less active would have the most to gain from being physically active, not only in terms of their health and wellbeing but also for motor function and gait, as shown in this experiment. However, there are two factors to account for when considering our results from self-reported PA levels. First, self-reported PA measurements are characterised by recall and social desirability bias (Celis-Morales et al., 2012) and low validity for assessing incidental PA (Strath et al., 2013). Consequently, future research should include objective measurements of PA and investigate PA in greater detail. Furthermore, previous evidence highlights the role of other movement behaviours, such as sedentary behaviour (SB), on disability and reduced physical function regardless of whether an individual participates in moderate to vigorous physical activity (Meneguci et al., 2021; Santos et al., 2012). Future studies investigating associations of movement behaviours (PA, SB) and their co-dependence with physical functioning and health are required to address this research gap.

In this study, older adults displayed age-specific walking adaptations which could be explained by physiological changes in muscle activation and muscle strength. Indeed, the selection of a cautious walking strategy on flat surfaces and for obstacle-crossing may be related to natural age-related strength loss (Hahn et al., 2005). Decline in muscle strength is the primary parameter of sarcopenia, it is a progressive and generalised skeletal muscle disorder involving also physical functioning and affecting both metabolic and muscle health (Cruz-Jentoft et al., 2019). This disorder is also a possible contributor to reduced mobility and ability to engage in regular physical activity in older adults. Thus, the research question on the association between musculoskeletal health and mobility (identified as movement behaviours) needs to be further investigated. Previous studies involving age-related changes in walking demonstrated that muscle strength was a significant predictor of reduced gait speed (Cuoco et al., 2004) and the role of thigh muscles in predicting age-related changes in walking stability has been previously reported (Bailey et al., 2019). The results of this study further support this by highlighting that older adults require greater percentages of their neuromuscular capacity during walking than young and middle-aged adults. Specifically, the vastii (lateralis and medialis; VL and ML, respectively) were significantly challenged during the older adults walking trials, suggesting that the quadricep muscle group (RF, VL, VM and vastus intermedius) should be considered in the functional assessment of older adults, and targeted as a critical component of strength training in older adult populations.

There are factors to account for when considering the results from this Chapter. First, participants in middle age group (40-59 years, Table 6) displayed higher coefficient of variations than the other age groups for each gait phase on uneven surface and for coefficient of variation for swing phase on flat. This finding possibly reveals a lack of diversity in the middle age group, supporting the presence of a self-selected bias in my sample. Second, age-related gait changes were assessed with the participants walking at their usual speed. Recent evidence has highlighted that fast gait speed (defined as walking as fast as comfortably able) is a relevant predictor of future disability in older adults (Artaud et al., 2015). Therefore, future studies assessing gait speed in older adults should include both measurements (usual and fast). Third, the presence of a self-selection bias should be accounted for. Bias is defined as any error resulting from recruitment methods affecting the study participation (Tripepi et al., 2010). As a consequence, the association found could differ between those included in the study and those potentially eligible for the study (including non-participants or non-responders) (Tripepi et al., 2010). Specifically, in this study, volunteers are thought to be in better physical shape than their same-age peers in the general population. Thus, care must be taken in generalising the results presented in this Chapter. Future studies involving volunteers should measure personal preferences and attitudes and control those individual factors as confounders during data analysis. Additionally, I used a limited self-reported measure of PA. This kind of measure could be influenced by social desirability bias and/or recall bias, as well as differences in perceptions of the meaning of PA. This could introduce errors that might lead to overestimations of the respondents' PA level assessed by self-report. Additionally, my question was limited to the exercise domain, while PA could be performed also for occupational and travel purposes. Therefore, future research should include standardised questionnaires and objectively-measure for PA data.

2.5 Conclusion

Age-related changes in the temporal parameters and neuromuscular activation of walking are present during the healthy ageing process. This study included high functioning adults, however we found differences in muscle activation dynamics and temporal gait parameters even in healthy physically active older adults. Consequently, the observed changes in temporal gait parameters and muscle activation dynamics could potentially be precursors and markers of future functional decline in older adults. Our findings from muscle activity could inform on appropriate motor patterns and efficient corrective responses to external perturbations that should be targeted in future interventions involving older adults. Additionally, our results suggest there is the possibility for middle-aged and older adults to achieve or maintain gait speeds equivalent to younger adults with high levels of PA. Therefore, given the presence of age-related changes in muscle activity and in functional task of walking on different surface conditions, the association between functionality and musculoskeletal health in older adults should be further investigated. However, individual intrinsic capacity is only one of the components of functional mobility in older people and this laboratory-based experiment can only provide a limited picture. Accordingly, I decided to further investigate older adults group’s daily levels and patterns of activities . This could be achieved by considering movement behaviours within the whole 24-h time period and influences of external factors such as economic, cultural, and context diversity in populations with the aim of detect early changes in musculoskeletal and cardiometabolic integrity to prevent future loss of mobility with ageing.

Chapter 3: Differences in 24-h movement behaviours in Scottish and South African communities

3.1 Introduction

In the previous Chapter, age-related effects on gait and muscular responses to different surfaces in Scottish adults and older adults were analysed. Higher muscular demand leading to an increase in walking effort and a cautious approach characterised older adults' walking behaviour. Previous evidence suggests that these age-related changes are associated with a reduced PA engagement and increases in PA are recommended to counterbalance the decline in lower limbs muscle strength in older adults. However, individual intrinsic characteristics are only one aspect of mobility in older people and laboratory-based experiments can only provide a limited picture. Indeed, the previous Chapter showed that there were differences, in a laboratory, in walking profiles and muscle recruitment. However, this work is limited in two respects. First, it was based on a somewhat narrow sample – young, middle-aged, and old individuals from the central belt of Scotland. Second, the previous results do not address differences in how physically active people are, their activity profiles across the day, and their physical strength. Therefore, it is important to translate research on older adults' mobility into the real world by including other variables, such as differences in socioeconomic setting and health status. Older adults living in South African townships have poorer health outcomes with higher rates of communicable and non-communicable diseases (NCDs), limited access to health care resources, and lower life expectancy compared to high-income settings (Abegunde et al., 2007). Consequently, older adults in LMICs are likely to experience a more serious impact on their wellbeing than tends to be experienced in HICs, along with a relevant economic burden. Therefore, in this Chapter we described a Scottish and a South African population and differences in their 24-h time use compositions.

Movement behaviours include all activities over a 24-h period across the movement spectrum, from no/little movement (sleep, sedentary behaviour) to movement of greater intensities (light physical activity and moderate-to-vigorous physical activity). Among movement behaviours, physical activity (PA) is a well-established key contributor for maintenance of healthy physical and mental health outcomes during ageing (Taylor, 2014; Lautenschlager et al., 2004). However, previous evidence highlighted that PA patterns and intensities are often dictated by socioeconomic status, with differences shown between low- to middle-income countries (LMICs) and high-income countries (HICs) (Gildow et al., 2016; Barr et al., 2020). Typically, older adults from HICs are more likely to engage in higher PA intensities (Strain et al., 2020), particularly moderate-to-vigorous PA (MVPA), thanks to a more favourable built environment and greater access to facilities for leisure-time activities that include gym-based exercise and sports (Strain et al., 2016). Conversely, older adults in LMICs tend to accumulate PA through occupational activities and walking for transport (Luo et al., 2020), typically completed at low(er) intensities (Gradidge et al., 2014). However, HICs are also characterised by higher volumes of sedentary behaviour (SB) mainly due to longer occupational and computer sitting time (Stamatakis et al., 2014) and time spent sitting as a means of transport (O'Donoghue et al., 2016). Notably, data from South African women indicate that in addition to high levels of light PA (LPA), there is also evidence of longer sleeping times (>9h per night) associated with negative health outcomes (Rae et al., 2018). Additionally, LMICs are characterized by a higher prevalence of obesity (Shisana et al., 2014), and greater burden of communicable, and non-communicable diseases (Mafuya et al., 2013) compared to HICs (McLean et al., 2018). Differences in living conditions and sociodemographic factors contribute to greater exposure and vulnerability of low socioeconomic communities to unhealthy behaviours and chronic diseases, leading to differences in general health status. However, there is limited research comparing objectively measured 24-h movement behaviours from men and women of similar age living in these settings.

As mentioned in the previous paragraph, along with differences in PA intensity, older adults from different socioeconomic backgrounds are characterised by differences in PA domains. Individuals from HIC display a greater engagement in leisure PA (Cerin & Leslie, Beenackers et al., 2012). Conversely, older adults in LMICs are shown to be a vulnerable group for leisure PA (Strain et al., 2020), with occupational and transport-based PA being the main contributor to their total PA. This phenomenon poses a challenge on PA related health outcomes, as previous evidence demonstrated that the majority of health benefits from PA are limited to the leisure domain (Holtermann et al., 2012). Indeed, recent studies highlighted the detrimental effect of occupational PA on cardiovascular health and all-cause mortality (Holtermann et al., 2018). Additionally, there is limited evidence on leisure PA participation in adults living in LMICs (Elshahat et al., 2020; Hulteen et al., 2017). Differences in time allocation of 24-h movement behaviours between diverse socioeconomic settings may represent an important target to improve research translation of behaviour into context-specific population health.

Previous evidence, supporting the need for a 24-h approach in movement behaviours research, highlighted the presence of methodological challenges that arise from the non-independence of these activity measures (Chastin et al., 2015). Indeed, time spent in each movement behaviour is related to the time spent in the other movement behaviours, meaning that by increasing the relative time spent in one behaviour another will decrease as they are measured in a discrete period of time (24-hours). To address this issue in the current and following chapters, compositional data analysis (CoDa) has been performed, which considers the intrinsic collinearity and co-dependence of movement behaviours (Chastin et al., 2015).

To date, no study has explicitly explored differences in time allocation for 24-h movement behaviours in older adults of similar age living in diverse socioeconomic settings in South Africa and Scotland. Further, there is limited research reporting objectively measured sleep duration in South African and Scottish older adults. Accordingly, this chapter aims to describe differences in PA patterns and time use composition of objectively measured 24-h movements in representative samples of older adults from Scottish and South African communities. Based on previous literature, we hypothesise that weekly PA, in the two cohorts, will have similar volume but will differ in intensity, with the Scottish community displaying higher intensities of PA.

3.2 Methods

I recruited and tested all of the Scottish participants; the South African participant data were collected by an exercise physiologist and 2 clinical research assistants at the University of Cape Town. I designed and conducted all of the analyses included in Chapter 3, 4, and 5 for both groups.

In this chapter, Scottish older adults (n=151) from a high-income urban setting and South African older adults (n=154) from a low-income urban setting, were recruited from local communities (churches, social clubs, and associations). The two settings were categorised according to the World Bank classification (World Bank, 2020). For the South African group, a convenience sample of volunteers community dwelling older adults were recruited from a low-income, urban setting with a demographic profile composing of black South Africans (). Specifically, participants were mainly recruited from Khayelitsha, a predominantly low-income area in Cape Town (Smit et al., 2016). South African older adults were recruited from senior community groups/clubs. For the Scottish group, a convenience sample of volunteers community dwelling older adults were recruited from high-income urban areas surrounding Stirling and Glasgow. Scottish older adults were recruited from senior community groups, charities for older adults, senior associations (Retired Police officers, Forth Valley University of Third Age, DanceSing UK), and snowballing through participants personal contacts. Inclusion criteria were the same for the two cohorts. Participants were aged 60-85 years, were ambulatory, living independently and able to understand verbal and written information about the respective studies. In the context of the South African population an older adult was classified as 60+ years based on the classification from the United Nations due to the low life-expectancy of 65.1 years for an individual (68.3 and 61.9 years for women and men, respectively) (Wang, 2020; Raut, 2019). Participants with diabetes were excluded from the Scottish study as required by the Scottish Ethics committee. The Scottish study was approved by the "West of Scotland Research Ethics Committee 3" (19/WS/0118). The South African study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (HREC REF:095/2018), and the NHS, Invasive or Clinical Research Committee at the University of Stirling (NICR:17/18). All participants provided verbal and written informed consent prior to commencing the study. The study was conducted in accordance with the 1964 Helsinki declaration and later amendments.

3.2.1 Study design

In this Chapter, methods for 24-h movement behaviours are described. In addition to movement behaviours, measures were taken for body composition, grip strength and gait speed, waist circumference and fat mass, blood pressure, and physical function tests. These will be considered separately in subsequent chapters. In this Chapter, results pertaining only to differences in 24-h movement behaviours are presented. Associations of movement behaviours and musculoskeletal health will be presented and discussed in Chapter 4. Associations of movement behaviours with body composition, adiposity, blood pressure, and physical functioning will be presented and discussed in Chapter 5.

Data collection protocols and methods for analysis were the same in the South African and Scottish studies unless otherwise stated. Data were collected over two testing sessions (**Figure 9**).

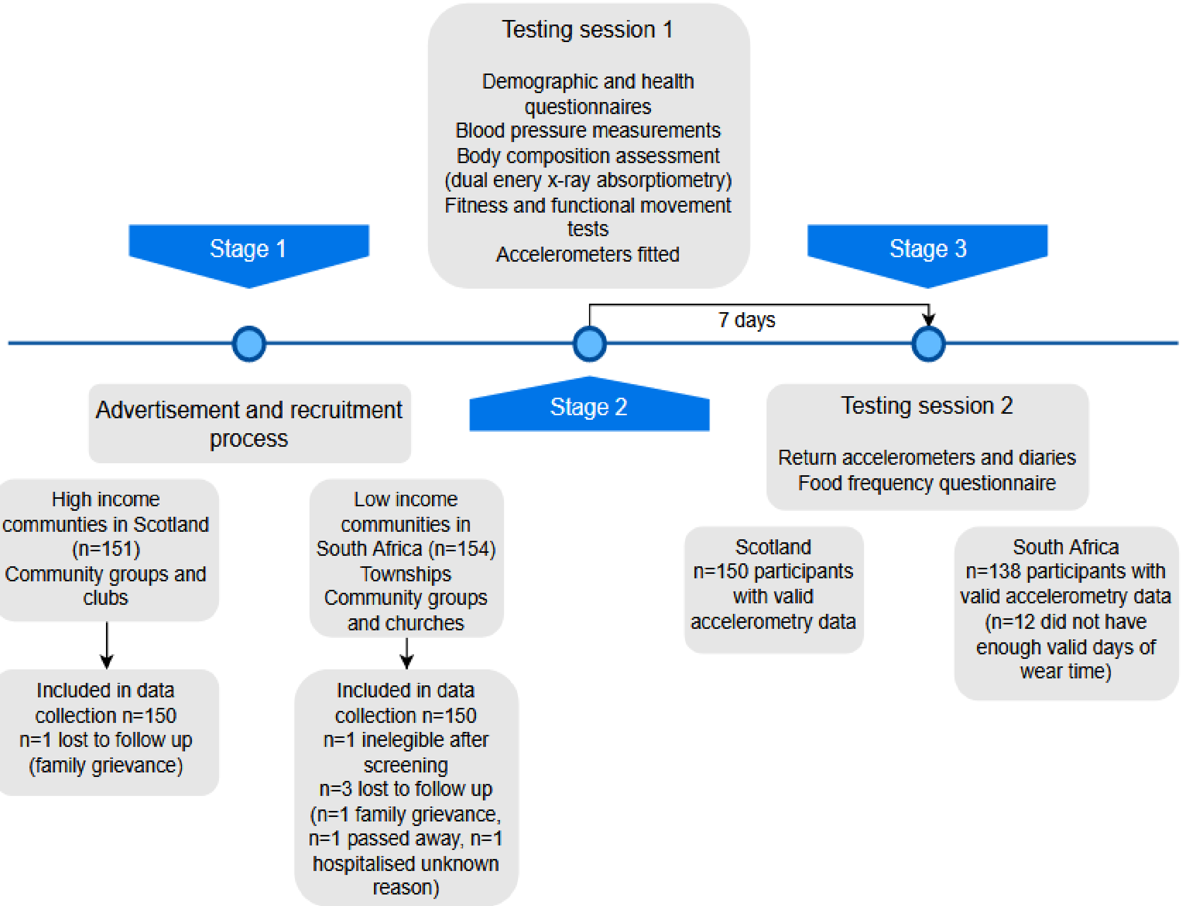


Figure 9. Study design.

During the first testing session (usually lasting 4 hours), demographic and health questionnaires were administered (Appendix 3). These included questions on housing density (ratio of the number of people living in the house relative to the number of rooms), smoking status (current and past smoking behaviours), as well as car ownership, civil status, and employment. Participants were also asked if they had fallen in the past year. A fall was defined as “any time you unexpectedly (or unintentionally) landed on the floor or ground” (Zecevic et al., 2006). A questionnaire was administered to assess sleep quality during the first testing session (Appendix 4). On the second testing session, after 7 days of wearing monitors, participants filled a questionnaire on diet related to their food intake in the week and returned monitors with diaries (Appendix 5). Participants from both settings were reimbursed for travel costs.

3.2.2 Body composition

Body mass was measured to the nearest 0.1 kg using a digital weighing scale (Scotland: Soehnle Connect, Soehnle-Waagen GmbH and Co.KG, Murrhardt, Germany; South Africa: BW-150, NAGATA, Tainan, Taiwan) in light-weight clothing without shoes, and height was assessed to the nearest 0.1 cm using a portable stadiometer (Scotland: Seca 213, Birmingham, UK; South Africa: 3PHTROD-WM, Detecto, Missouri, USA). Body mass index (BMI) was computed as body mass (kg)/height (m^2) and classified according to World Health Organization (WHO) criteria (World Health Organisation, 1998).

3.2.3 Movement behaviours

Movement behaviours (MVPA, LPA, SB, sleep) were measured simultaneously with an Actigraph (GTX3+, ActiGraph LLC, Pensacola, Florida) and ActivPAL (PAL Technologies Ltd, Glasgow, Scotland), both of which were worn for 7 consecutive days (**Figure 10**). They are validated instruments to measure movement behaviours in older adults (Santos-Lozano et al., 2013; Sellers et al., 2016). The Actigraph monitor was attached to the waist over the right hip with a lightweight belt (Duncan et al., 2020) and initialised to collect data at 80 Hz, while the ActivPAL was attached on the mid anterior right thigh with waterproof dressing (Edwardson et al., 2017). This tri-axial inclinometer provides accurate and reliable measurement of SB and it categorises time spent in sitting or upright posture based on thigh inclination (Kozey-Keadle et al., 2011). On the day of the trial a trained researcher provided verbal, visual, and written instructions on how to wear the monitors correctly and checked participant understanding. Participants wore the monitors 24-h/day removing only for water-based activities (as bathing, swimming, or showering). Participants were asked to complete a written log to indicate times when the monitors were not worn. A second log was used to collect information on sleep behaviour including time going to sleep and waking up. Activity counts were measured in 60-second epochs, and data were processed using ActiLife 6 software (ActiGraph Inc, Pensacola, FL, USA) and PAL analysis (CREA beta-algorithm, PAL analysis, Version 8.11.2.54).

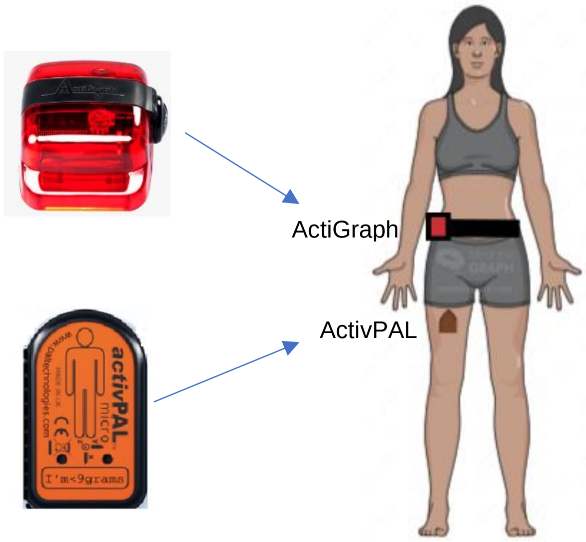


Figure 10. Monitor locations used, ActiGraph (red colour) was placed on the right hip. ActivPAL (orange colour) was placed on the right thigh. ActiGraph picture taken from ActiGraphcorp. ActivPAL picture taken from PAL technologies LTD.

3.2.4 Accelerometry data management

Both monitors were returned on the second testing session along with diaries. Most of the Scottish participants spontaneously reported detailed activity log diaries specifying their social activities, leisure sports, and routinely activities. Three main steps were performed for accelerometry data analysis. Firstly, a trained researcher identified periods of nocturnal sleep by visual inspection rules (Chow et al., 2016), looking for decline in activity counts in ActiLife outputs. Sleep diaries were used to check participant reported sleep times where nocturnal sleep periods were difficult to identify. Nocturnal sleep duration, referred to as 'time in bed' (TiB, minutes) was used as primary measure of sleep duration/sleep quantity and it was used for analysis (averaged across all night of measurements). Sleep duration/quantity has been derived from accelerometry data. Sunday to Thursday night were considered as weeknights, while Friday and Saturday night were represented as weekend nights (Evenson et al., 2015). To be included in valid sleep dataset a participant needed to have at least 3 sleep nights (defined as >160 minutes of sleep time) including at least one weekend night. Following the identification of nocturnal sleep periods, the remaining accelerometry wear time was checked for the other movement behaviours (PA and SB). A valid PA and SB data set comprised of at least 4 days of valid wear time. A single valid day was defined as a day with 600 minutes of wear time, following the exclusion of any other non-wear periods (non-wear time was defined as 60 minutes of consecutive zeros with allowance for two minutes of activity counts between 0 and 100). SB, LPA, and MVPA were classified using established cut-offs, as previously used in NHANES: sedentary

<100 cpm, total PA ≥100 cpm, 100 < LPA < 2020, MVPA ≥2020 cpm (Troiano et al., 2008). The duration of time spent in each activity behaviour was determined (mins/day), and all behaviours accounted for whole participant daily time (1440 minutes). ActivPAL data were analysed with all participants presenting with a minimum of seven consecutive 24-hour days. Wear time included a 24-hour protocol, allowing for 4 hours of non-wear time, minimum of 10 s non-upright and upright periods. Daily step count and number of sit to stand transitions, standing, stepping sitting, time spent upright (total of standing and stepping time), and total time spent in sedentary bouts of more than 30 and 60 minutes are reported.

3.2.5 Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) was used to evaluate sleep quality. The PSQI has been previously validated in high (Buysse et al., 1989) and low-income settings (Aloba et al., 2007). It consists of 19 self-rated items referring to the previous 4 weeks. This questionnaire provides a total score (>5 indicates poor sleep quality) along with seven sub-components: habitual sleep efficiency, subjective sleep quality, sleep disturbances, use of medication, daytime dysfunction, and sleep latency. Each of the seven components have a range of 0-3 points where “0” indicates no difficulty and “3” indicates severe difficulty.

3.2.6 Sleep and physical activity recommendations

To assess sleep patterns, participants were classified according to National Sleep Foundation (NSF) recommendations (Hirshkowitz et al., 2015). Participants were considered as meeting sleeping recommendations if they accumulated 7-9 h of sleep per night, while older adults were considered to meet recommendations if their nocturnal sleep was between 7 and 8 h. Adults sleeping less than 6 h and older adults sleeping less than 5 h were considered as sleeping too little, while participants were sleeping too much if they accumulated more than 10 h of sleep for adults and more than 9 h of sleep for older adults.

Participants were classified as meeting PA guidelines according to the most recent WHO guidelines (Bull et al., 2020) on aerobic PA (do at least 150-300 minutes of moderate-intensity aerobic PA; or at least 75–150 minutes of vigorous-intensity aerobic PA; or an equivalent combination of MVPA, throughout the week).

3.2.7 Statistical Methods

Only statistical methods regarding the description of differences in 24-h movement behaviours in Scottish and South African older adults are addressed here. Analysis was conducted using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA), while compositional analysis was conducted using the open-source software Physical Activity CoDa Regression Model (PACRM) and CoDa Pack v2.03.01 (McGregor et al., 2018). Contextual information from Scottish activity diaries were imported from Excel into NVIVO v12 Pro for Windows and analysed with conventional content analysis (Hsieh & Shannon, 2005). Traditional descriptive statistics were stratified according to Scottish and South African groups. The normality of the data was analysed by the Kolmogorov–Smirnov test combined with Q-Q plots. Descriptive statistics for continuous variables were expressed as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Categorical variables were expressed as frequency and percentage. PA variables were presented as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. For compositional data analysis, compositional means of movement behaviours were considered. $\chi 2$ (Chi-square) or Fisher exact test (where appropriate) was conducted to determine differences for categorial variables.

A compositional multivariate analysis of variance (MANOVA) on isometric transformed data was used to determine differences in time use composition between Scottish and South African participants (independent variable) (Gupta et al., 2018). To interpret differences between movement behaviours we developed bootstrap percentile 95% confidence intervals (Gupta et al., 2018). We firstly checked assumptions for MANOVA and as they were not violated, we calculated an unadjusted MANOVA model and later considered covariates based on previous literature (Scott et al., 2020). Covariates in the model included: age, sex, BMI, education, and smoking status, as well as HIV and diabetes presence in the South African sample. A sensitivity analysis for 24-h movement behaviours group differences excluding South African participants with diabetes and HIV was performed. Statistical significance was set at $P < 0.05$.

3.3 Results

Results for sarcopenia components, bone mineral density, body composition, adiposity, and functional movement tests will be discussed in Chapters 4 and 5.

3.3.1 Participants' characteristics

Age and sex did not differ between the South African and Scottish cohorts. However, compared to the Scottish cohort, South African participants reported a lower socioeconomic status, which was reflected in a higher housing density, lower level of education, and lower car ownership (**Table 7**). Scottish older adults reported a significantly higher energy intake (P<0.01). Smoking behaviour, civil and employment status did not differ between the two cohorts. In the South African group, 22.5% of participants had diabetes and 8.7% were living with human immunodeficiency virus (HIV). Falls in the last year were reported by 42% of Scottish older adults and 58% of the South African older adults, and this was significantly different between the cohorts (P=0.04).

Table 7. Descriptive characteristics of Scottish and South African cohorts

Variables	Scottish cohort (n=150)	South African cohort (n=138)
Age (years)	69 (66-73)	68 (64-71)
Sex (n, %), Females	117 (78)	113 (82)
Education (n, %)		
Less than secondary	**13 (9)**	**72 (52)****
Completed secondary	**27 (18)**	**65 (47)**
Completed tertiary	**110 (72)**	**1 (1)**
Housing density	**0.3 (0.2-0.3)**	**1 (0.6-1.4)****
Smoking status (n, %)		
Never smoked	94 (63)	100 (73)
Previous smoker	53 (35)	22 (16)
Current smoker	3 (2)	16 (12)
Car owner (n, %)	**141 (94)**	**17 (12)****
Civil status (n, %)		
Single	30 (20)	55 (40)
Married or living with a partner	105 (70)	25 (18)
Widowed	15 (10)	58 (42)
Employed, yes (n, %)	3 (2)	0
MVPA (min/week)	**153 (88-265)**	**64 (18-128)****
Meeting PA guidelines ≥150 min/week (n, %)	**77 (51)**	**28 (20)****
Meeting sleep recommendations (n, %)	41 (27)	32 (23)
Sleeping within the appropriate range (n, %)	**76 (51)**	**36 (26)****
Sleeping too short (n, %)	**0**	**6 (4)***
Sleeping too long (n, %)	**33 (22)**	**64 (45)****
Fallen in past year, yes (n, %)	**32 (42)**	**44 (58)***

*All normally distributed and skewed data are reported as mean ± SD and median (IQR, 25-75th percentile), respectively. Abbreviations: MVPA, moderate-to-vigorous physical activity. PA, physical activity. P values represent a significant difference between groups. Parametric and non-parametric (Mann-Whitney U, Kruskal Wallis) independent t-tests were conducted on normally distributed and skewed data, respectively. Chi-square was used to determine differences in frequency of each variable between Scottish and South African cohorts. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

3.3.2 Movement behaviours

A total of 150 participants were included in the analysis for the Scottish cohort, with one participant's data was excluded due to invalid accelerometry data. 138 participants provided valid accelerometry data in the analysis for South African group. A total of 3 older adults were lost at the follow up (n=1 hospitalised for unknown reason, n=1 passed away, n=1 family grievance) and one participant was considered ineligible after screening. Scottish and South African older adults accumulated similar amounts of total PA over the week period and showed significant differences between groups in each movement behaviour (**Table 8** and **Table 9**) and 24-h time-use composition (**Figure 11**). Results from the bootstrap percentile 95% confidence interval are presented in **Figure 11**. Lines falling above the dotted line indicate that relative time spent in the specific behaviour was higher in the Scottish cohort compared to South African cohort. Conversely, lines falling below the dotted line indicate that the component was higher in the South African sample. The geometrics means, used for the 24-h time-use composition analysis, are shown in **Table 8**. In particular, Scottish participants spent more time in MVPA and SB relative to the other behaviours compared to the South African counterpart. Alternatively, South African older adults spent more time in LPA and had longer nocturnal sleep duration relative to the other behaviours. According to the most recent WHO recommendations for PA, the threshold of 150 minutes of combined MVPA was achieved by 51.4% of the Scottish cohort and 20.3% of the South African cohort. Among individuals meeting WHO PA recommendations, 18.7% of the Scottish and 6.5% of the South African older adults completed 300 minutes or more of MVPA during the week. No significant differences were found in the number of people meeting NSF sleep recommendations in the two cohorts (**Table 7**). However, a higher percentage of Scottish older adults had an appropriate number of sleeping hours (50.7% vs. 25.5%, $P<0.01$), while a greater percentage of South African participants were sleeping too long (45.4% vs. 22.0%, $P<0.01$). Alongside longer nocturnal sleep, the South African cohort reported a greater number of sleep disturbances and daytime dysfunction, higher use of sleeping medication, worse sleep latency, but greater sleep efficiency than the Scottish older adults (**Table 10**). However, no differences in the overall PSQI score were found between cohorts. Cronbach's alpha internal consistency for this questionnaire in the Scottish sample was 0.75, while in the South African cohort was 0.71. Additionally, 58 Scottish older adults reported trouble sleeping because of other reasons (question 10 of the

PSQI). The most common described reason was family issue and concern (n=15). Other reasons highlighted were pain (n=6) and anxiety (n=5).

Table 8. Movement behaviours compositional MANOVA model between Scottish and South African cohorts

Variables	**Scottish (n=150)**	**South African (n=138)**
SB (min/day)	**604**	**551***
LPA (min/day)	**288**	**312****
MVPA (min/day)	**20**	**6****
Nocturnal TiB (min/day)	**523**	**569****

*Time use composition data are reported as compositional means (mins/day). Movement behaviours have been normalised to 1440 minutes. Abbreviations: SB, sedentary behaviour. LPA, light physical activity. MVPA, moderate-to-vigorous physical activity. TiB, time-in-bed. Results of Multivariate Analysis of Variance (MANOVA) of differences in time spent in sedentary behaviours, light physical activity, moderate-to-vigorous physical activity, and sleep between Scottish and South African groups, analysed using CoDa approach. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

Scottish older adults' daily step count was significantly higher than South African individuals (P<0.05). However, Scottish participants had a greater amount of sitting time with about 9 hours per day spent sitting vs. 7 hours in the South African cohort (P<0.01). Scottish participants also displayed significantly longer sitting bouts of 30 and 60 minutes compared to South African counterpart. Conversely, South African older adults had significantly longer upright and standing time (P<0.01), but similar amount of stepping time compared to Scottish participants (P=0.19). No significant difference in the daily number of sit to stand transitions was found (P=0.10). However, a tendency for a difference is present with Scottish older adults displaying a higher number of sit to stand transitions compared to the South African group.

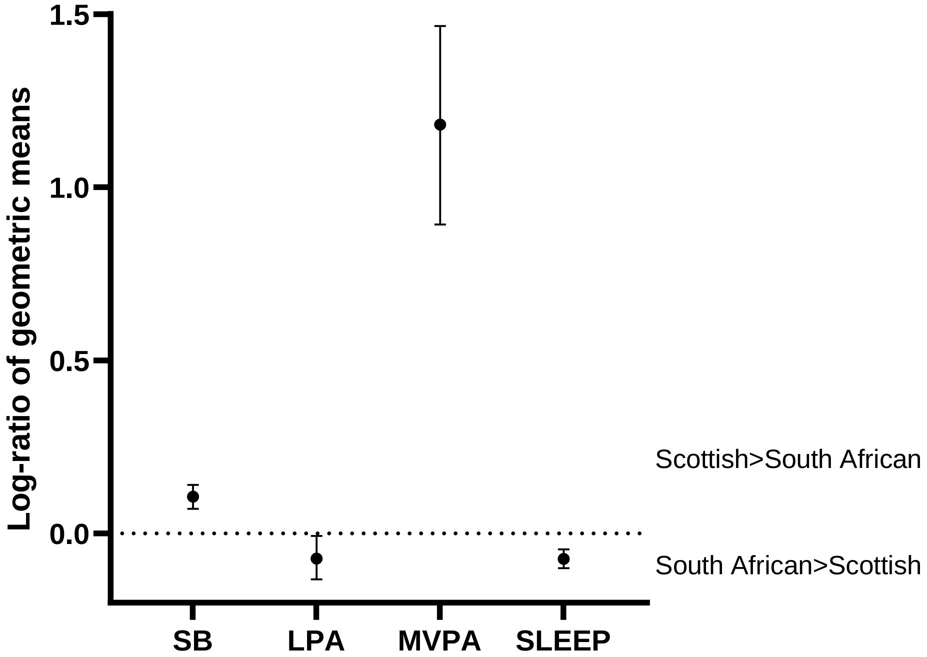


Figure 11. Log-ratio (95% confidence intervals) difference between the Scottish and South African groups for each movement behaviour.

Table 9. Movement behaviours differences between Scottish and South African cohorts

Variables	**Scottish cohort (n=150)**	**South African cohort (n=138)**
	Actigraph	
Accelerometer total wear time (min/day)	**913 ±46**	**878 ±80****
Average weekly PA (min/week)	324 ± 64	334 ± 96
SB (h/day)	**10 (9-118)**	**9 (8-10)****
LPA (min/day)	**287 ±55**	**318 ±92****
MVPA (min/day)	**27 (15-44)**	**11 (3-21)****
Nocturnal TiB (h/night)	**8 ±1**	**9 ±1****
SB (%daily wear time)	**41 (38-44)**	**37 (34-41)****
LPA (%daily wear time)	**20 ±4**	**22 ±6****
MVPA (%daily wear time)	**2 (1-3)**	**1 (0.2-2)****
Nocturnal TiB (%daily wear time)	**36 ±3**	**39 ±5****
	ActivPAL	
Daily step count (n)	**8020 (6291-10560)**	**7309 (3432-9247)****
Upright time (min/day)	**353 ±84**	**413 ±126****
Standing time (min/day)	**246 ±73**	**312 ±108****
Stepping time (min/day)	99 (83-126)	100 (75-121)
Sitting time (h/day)	**9 ±2**	**7 ±2****
Sit to stand transitions (n/day)	41 ±9	38 ±13

Sitting time bouts >30 min (min/day)	**284 ±107**	**216 ±96****
Sitting time bouts >60 min (min/day)	**137 (85-205)**	**94 (49-162)****
*All normally distributed and skewed data are reported as mean ± SD and median (IQR, 25-75th percentile), respectively. Movement behaviours data are reported as traditional mean or median (min/day) and %. Abbreviations: PA, physical activity. SB, sedentary behaviour. LPA, light physical activity. MVPA, moderate-to-vigorous physical activity. TiB, time in bed. P values represent a significant difference between groups. Parametric and non-parametric (Mann-Whitney U, Kruskal Wallis) independent t-tests were conducted on normally distributed and skewed data, respectively. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*		

Table 10. Differences in sleep parameters from the Pittsburgh Sleep Quality Index questionnaire between Scottish and South African cohorts

		Scottish (n=150)	South African (n=138)
Sleep efficiency (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	**52 (34.7)** **34 (22.7)** **40 (26.7)** **24 (16)**	**73 (52.9)**** **25 (18.1)** **16 (11.6)** **24 (17.4)**
Subjective sleep quality (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	30 (20) 77 (51.3) 37 (24.7) 6 (4)	30 (21.7) 72 (52.2) 23 (16.7) 10 (7.2)
Sleep disturbances (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	**3 (2)** **114 (76)** **31 (20.7)** **2 (1.3)**	**0**** **48 (34.8)** **73 (52.9)** **17 (12.3)**
Use of medication (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	**63 (42)** **82 (54.7)** **5 (3.3)** **0**	**89 (64.5)**** **2 (1.4)** **18 (13)** **29 (21)**
Daytime dysfunction (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	**63 (42)** **82 (54.7)** **5 (3.3)** **0**	**22 (15.9)**** **53 (38.4)** **53 (38.4)** **10 (7.2)**
Sleep latency (n, %)	0, no difficulty 1, fairly good 2, fairly bad 3, severe difficulty	**37 (24.7)** **59 (39.3)** **35 (23.3)** **19 (12.7)**	**33 (23.9)**** **25 (18.1)** **39 (28.3)** **41 (29.7)**
*Results for sleep sub-components are reported as total number and percentage. Kruskal Wallis test was used to determine differences in frequency of each variable between Scottish and South African cohort. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*			

3.3.3 Sensitivity analysis

In the compositional MANOVA model for the South African sample, we adjusted for the two main diseases that were different in the cohorts (HIV and diabetes). Diabetes and HIV were not significant contributors in this model. Results of the sensitivity analysis on the subsample of South African participants (excluding diabetes and diabetes + HIV) are presented in **Table 11**. Statistical significance from these models follows the same pattern as the models presented in **Table 8**. Specifically, each movement behaviour was significantly different across the 2 cohorts.

Table 11. Subsample analysis for multivariate analysis of variance of 24-h movement behaviours

Variables	**Scottish cohort (n=150)**	**South African cohort (no diabetes, n=107)**
SB (min/day)	**604**	**550****
LPA (min/day)	**288**	**319****
MVPA (min/day)	**25**	**9****
Nocturnal TiB (min/day)	**523**	**563****
Variables	**Scottish cohort (n=150)**	**South African cohort (no diabetes and no HIV, n=98)**
SB (min/day)	**604**	**548****
LPA (min/day)	**288**	**325****
MVPA (min/day)	**25**	**9****
Nocturnal TiB (min/day)	**523**	**558****

*Time use composition data are reported as compositional means (mins/day). Movement behaviours have been normalised to 1440 minutes. Abbreviations: SB, sedentary behaviour. LPA, light physical activity. MVPA, moderate-to-vigorous physical activity. TiB, time-in-bed. Results of Multivariate Analysis of Variance (MANOVA) of differences in time spent in sedentary behaviours, light physical activity, moderate-to-vigorous physical activity, and sleep between Scottish and South African groups, analysed using CoDa approach. Statistically significant results are highlighted in bold: *p<0.05,**p<0.01.*

3.3.4 Content analysis of Scottish activity log diaries

The overwhelming majority of participants reported that the week of accelerometry data collection represented a typical week. Six main categories of activities were identified when analysing the activity log diaries from Scottish participants. These included: 1) structured physical activities (e.g. exercise classes), 2) unstructured physical activities (e.g. housework), 3) travel, 4) sedentary activities, 5) social activities, and 6) caring activities. Additionally, several participants provided substantial detail of duration of specific activities, however due to a lack of consistency across participants this information was not included in the analysis. **Figure 12** is an extract of a representative example of a detailed activity diary from a man (aged 75 years), while in **Figure 13** one of the least detailed accounts is presented from a man (aged 71 years) on the same day of data collection. Additionally, we included an extract of diaries from two women aged 61 and 83 years old, respectively (**Figure 14** and **15**). This information provides an illustration of the activities reported in the Scottish community sample.

DATE	TIME		ACTIVITY
	START	END	
10/2/2020, Monday	06.20		Up briefly for toilet
	07.00	08.50	Wake up + start morning routine
	08.50	09.12	Showering so sensors off
	09.12		Sensors back on
	09.12	10.05 (approx.)	Preparing to go out
	10.05	11.15	Shopping (walk into town)
	11.15	12.45	On computer + other admin
	12.45	14.00	Preparing + having lunch + washing up
	14.00	15.30	More admin
	15.30	16.10	Resting, very tired
	16.10	16.30	Walk to post letter
	16.30	17.30	Just doing minor things in the flat
	17.30	19.20	Preparing evening meal, eating, washing up
	19.20	22.05	Watching TV
	22.05	22.55	Reading
	23.00		Sleep

Figure 12. Extract of a detailed activity log diary from a Scottish male aged 75 years old (for full diary picture provided please see Appendix n 6).

Each day	1 or 2 dog walk 30 minutes – 1 hour
Tuesday + Thursday	1 hour pilates class
Each day	Monitors taken off for 30-45 minutes in the morning for a shower
Swimming 7/2/2020	5-6.30pm monitors off

Figure 13. Example of activity log diary from a Scottish male aged 71 years old (picture provided please see Appendix n 7).

Friday 28th February	
9-10.45	Gym+ salsa class
	Walk to and from gym (approx. 1 mile)
1.30-5.00	DIY-painting
6.30-7.30	Housework
7.30-12.00	Reading/TV

Saturday 29th February	
9.30-11.30	DIY-painting
11.30-12.15	Walk (2 miles)
1.00-3.00	Shopping/driving
3.00-5.00	Housework
5-8	Out at event
8-10.30	Looking after children

Figure 14. Extract of activity log diary from a Scottish female aged 61 years old (for full diary picture provided please see Appendix n 8).

04/03/2020	Yoga exercises 7-7.30am
05/03/2020	Gym-weight training with personal trainer
06/03/2020	Yoga exercises 7-7.15am Sports massage (removed monitor from waist) Shopping for food
09/03/2020	Weight training gym session 8-9am

Figure 15. Activity log diary from a Scottish female aged 83 years old (picture provided please see Appendix n 9).

We considered structured physical activities as those that were planned or scheduled exercise sessions. The most common structured physical activity mentioned was walking (mentioned over 260 times), followed by exercise class, with over 60 individuals reporting engagement in fitness classes during the week of data collection. Exercise in the gym and Pilates were respectively reported as frequent structured activities, with an average of 30 older adults taking part in these activities. The most common unstructured activities reported were respectively: housework, shopping, gardening, and DIY. For the travel category, travel by car was the most reported means of transport (mentioned 150 times). Few participants reported walking (as a means for active travel) and public transport in their activity log diaries. Sedentary activities performed at home mainly consisted of reading time, puzzles, paperwork and admin, table games, and studying (languages or music). The most common social activities in our cohort were: meeting friends, playing bridge, going to the cinema, going to the church, and volunteering. Although less common, caring responsibilities such as looking after grandchildren or other family members was also reported (mentioned 25 times).

3.4 Discussion

In this Chapter, we described and compared 24-h movement behaviours of older adults from South African and Scottish communities. Although the total amount of weekly PA between the two cohorts was similar, there were differences in the relative time spent in each movement behaviour. Specifically, Scottish participants spent more relative time in SB and MVPA, with longer sitting time and greater number of older adults meeting WHO PA recommendations. Conversely, South African older adults spent more time in LPA and nocturnal sleep relative to the other behaviours. Our results suggest that interventions targeted at movement behaviours in older adults should consider the influence of the socioeconomic setting on 24-h time use compositions, acknowledging differences in PA domains among groups of older adults from diverse settings.

3.4.1 Scottish sample

In our cohort, more than the half of older adults were meeting PA guidelines (≥150 min) and almost the 20% achieved the 300 minutes threshold recently introduced by the WHO in the latest recommendations released in November 2020 (Bull et al., 2020). Our finding agrees with previously published pre COVID-19 prevalence of meeting PA guidelines from the Scottish Health Survey conducted in 2019 (Scottish Health Survey, 2019). Specifically, 55% of older adults aged 65-74 reported achieving the recommended threshold for aerobic PA (Scottish Health Survey, 2019). In our sample, the major contributor to PA appears to be walking (although not for active travel, which may be because participants omitted that detail when reporting other structured activities such as going to the gym, or due to the data collection period overlapping with the seasons characterized by wetter Scottish weather), indeed it was the most reported structured PA, followed by fitness classes and non-team sports. This finding supports previous evidence of an increase in walking participation with ageing and that although participation in aerobics/fitness activities decreased with age, it was still prevalent amongst adults aged 50+ (Hulteen et al., 2017). Additionally, a previous study on Scottish individuals reported that both active and insufficiently active older adults took part in activities in the domains of exercise & fitness and non-team sport, however walking was the main contributor to total MVPA (Strain et al., 2016). Therefore, future research should further assess the range of domains in which PA in older adults takes place and their impact on health outcomes.

A large number of Scottish older adults were evidently engaging in appropriate amount of PA in this study, however, they displayed high amount of SB. Indeed, they spent ~10 h (and ~9 h of sitting time) of the day in SB, and in line with the most recent recommendations by the WHO, this may have detrimental effects on the risk of developing chronic diseases and increase mortality rates (Gonzalez et al., 2017). Our finding is in agreement with previous evidence (Strain et al., 2018; Leask et al., 2015; Lord et al., 2011) and previously reported values of SB in Scottish older adults (Scottish Health Survey, 2019). In Scotland, information on population’s SB is collected annually with a survey (Scottish Health Survey) including self-reported questions on occupational sitting time, leisure screen time, and other leisure SB. The most recent report showed an increase in SB with advancing age, specifically older adults aged 65+ reported an average of 7.5 hours of daily SB (Scottish Health Survey, 2019). Previous studies considered SB in isolation and/or collected data on SB with self-reported measures of TV viewing and screen time (Bauman et al., 2018), however they have low to moderate validity and represent a restricted number of circumstances in which this behaviour is taking place (Atkin et al., 2012). Thus, the novelty of our findings is in the consideration of the time spent across the entire 24-h day and the use of objective measures. SB is a modifiable risk factor for poor health status and poor functional mobility in older adults (Wilson et al., 2019; Harvey et al., 2018). Therefore, to sustain beneficial effects that PA has on different health outcomes with ageing, older adults should be supported to maintain PA levels, while reducing SB.

In this sample, we have been able to collect contextual information on activities during the week of data collection. Feedback provided was variable, however information reported are helpful to better characterise the cohort. A notable finding is that even if Scottish older adults spent 41% of daily wear time in SB, they reported mostly active SB with reading and studying activities, playing table games, and dealing with admin or paperwork. Previous evidence demonstrated that higher passive sedentary time was associated with higher odds of being overweight and higher psychological distress (Kessler K6 scale) in Japanese older adults (Kikuchi et al., 2014). A recent review reported potentially relevant differences between passive and mentally active SB on depression, with the latter having a protective effect on depression onset (Hallgren et al., 2020). Therefore, considering different domains of SB based on context and type could provide more appropriate information for future recommendations. Additionally, to obtain reliable contextual information from older participants on daily activities logs and/or diaries with specific activities questions should be included in future studies.

3.4.2 South African sample

On average, South African older adults in our sample displayed 64 minutes of weekly MVPA and only 20% of the participant met recommended level of PA. A limited number of studies examined PA in older adults in South Africa and LMICs and the majority of them relied on self-reported measures of PA. Reported levels of physical inactivity (defined as engaging in less than 150 minutes of MVPA per week) ranged between 40% of older adults in residential care facilities (Aro et al., 2018) to 69% of adults 50+ years from a South African population-based survey in 2012 (Mlangeni et al., 2018). The restricted number of people meeting PA guidelines could be explained by the high prevalence of women (82%) included in our study, indeed previous evidence highlighted older adults and women as vulnerable groups for low levels of PA in South Africa (Mlangeni et al., 2018; Peltzer & Phaswana-Mafuya, 2012) as well as Sub-Saharan LMICs (Guthold et al., 2011). Few studies reported the estimated prevalence of SB in older adults (Koyanagi et al., 2018; Phaswana-Mafuya et al., 2018). The few available African studies highlighted greater risk of high levels of SB (defined as ≥8 h per day of SB) with advancing age, low socioeconomic status, and adverse clinical condition (Phaswana-Mafuya et al., 2018). Therefore, an increased need for more context-specific research in African settings is present. For example, a recent study found consistent associations between neighbourhood environmental attributes and SB in Nigerian older adults (Oyeyemi et al., 2019). As the Sub-Saharan burden of non-communicable diseases increases (Gouda et al., 2019), risk factors such as SB and physical inactivity become important targets for public health interventions in LMICs. Thus, Africa-specific studies on objective measures of 24-h movement behaviours can provide more targeted evidence for policy initiatives aimed at promoting less sitting time and more active living in the African region.

South African older adults had long nocturnal time in bed. However, previous values of self-reported sleep duration in South African older adults are lower compared to our findings. Specifically, self-reported sleep duration ranged from 8.5 h – 8.9 h per day (Hill et al., 2016; Peltzer, 2017) vs our objectively measured sleep duration of 9.5 h per night averaged across 7 week and weekend days. Correlates of longer sleep duration in this population were consistently associated with lower wealth and advanced age (60-79 years) (Peltzer, 2012). Several studies have highlighted a consistent association between sleep duration, obesity (Gildner et al., 2014), and increased prevalence of chronic diseases and related risk factors (Mesas et al., 2010). Indeed, previous evidence indicates that both long and short sleep durations are associated with poorer health outcomes in adults and older adults (Zawisza et al., 2015), suggesting the presence of a U-shaped relationship between sleep duration and sleep quality with health markers (Lauderdale et al., 2016). Evidence from dose–response analysis showed that the sleep duration was most favorably associated with better health outcomes with 7–8 h of sleep at night (Chaput et al., 2020), emphasizing the dimension of sleeping behaviours as an emerging public health target to improve general health in older adults living in low socioeconomic settings. However, few studies investigated sleep habits of South African older adults with objectively measures of sleep duration.

3.4.3 Comparison of Scottish and South African samples

The representative samples of older adults from the Scottish and the South African communities had significantly different time use compositions of 24-h movement behaviours. Specifically, Scottish older adults displayed higher relative time in MVPA compared to the South African counterpart. This finding agrees with previous evidence highlighting high engagement in MVPA in high-income settings (Scholes & Mindell, 2020). Conversely, we found low time spent in MVPA relative to the other behaviours in the South African sample with a restricted number of older adults meeting PA recommendations for aerobic exercise, common issues of LMICs (Barr et al., 2020). This finding could be explained by the fact that most of the South African participants involved in the study were either unemployed or retired, leading to a greater amount of time spent in LPA. No contextual information from this cohort was collected but previous research has shown that South African older adults accumulate their MVPA in the occupational domain and to lesser extent participation in leisure activities (Barr et al., 2020; Cleland et al., 2019). Thus, future interventions and policies involving movement behaviour(s) targeted to enhance health in older adults should consider economic diversity in populations.

When considering behaviours such as PA, a holistic definition should be considered to allow the inclusion of dynamic, cultural, environmental, and political aspects affecting opportunities and constraints to PA engagement (Piggin, 2020). In the comparison of samples of older adults from the Scottish and the South African communities, cultural and traditional values should be considered. South Africa has the highest obesity prevalence rates in Africa and it is higher among South African females, with a prevalence of 39% among females as opposed to 11% among males (Human Sciences Research Council, 2013). However, cultural and traditional values have an influence on the prevalence of larger body size among South African females. Larger body size is generally viewed as a sign of beauty, health, affluence, and absence of disease or illness including HIV (Alaba & Chola, 2014). A qualitative study involving 32 South African women investigated perceptions on diet, physical activity, and obesity-related health (Phillips et al., 2016). Participants were aware of the benefits of PA, but either reported personal reasons (having other priorities, preference for sedentary activities, or not enjoying PA) or faced barriers to engage in PA (lack of time, lack of money, lack of access to sports teams, or feeling tired) (Phillips et al., 2016). In LMICs such as South Africa, the association between the built environment and PA should be also taken into account. For example, in a convenience sample of urban-dwelling South Africans, self-reported leisure time and MVPA were significantly higher in people living in areas in which crime was not perceived to be a problem (Micklesfield et al., 2013). This finding is further supported by a cross sectional study on 1818 participants aged 20-65 years old living in Nigeria (Oyeyemi et al., 2012). The study showed that perceived safety, aesthetics, and cleanliness were positively associated with PA (Oyeyemi et al., 2012). Therefore, cultural and contextual factors should be considered across diverse countries and socioeconomic settings and future studies should also consider investigating populations from different socioeconomic backgrounds within the same country.

Furthermore, analysis of the PSQI subcomponents showed that the South African participants reported more sleep disturbances, longer sleep latency, higher use of medication and more day-time dysfunction. These results could be related to the higher housing density in the South African group (three times more than the number of people per room in Scotland). Indeed, previous studies have shown that 42% of the people living in South African townships indicated that between five and ten people were living in the housing unit allotted to them (Peberdy & Majodina, 2000), and specifically 81.1% were sharing sleeping space or bedroom (Moolla et al., 2011). Conversely, the most common reason for sleep problems in the Scottish cohort were family concerns, anxiety, and pain. Poor sleep quality and age-related changes in sleep patterns have been shown to have adverse effects on health during ageing, particularly on mental and physical health (Gadie et al., 2017). Therefore, research should assess and investigate the effect of differences in sleep quality and sleep duration across diverse socioeconomic settings on health in older adults.

There are factors to account for when considering the results from this chapter, some of which will be addressed at a later stage in the thesis, and some which will be recommendations for future research. First, due to ethics requirements, older adults with diabetes were not included in the Scottish cohort. Consequently, our findings cannot be generalized to the whole HIC older adult population. However, the results and statistical significance obtained from the sensitivity analysis excluding South African participants with diabetes and HIV followed the same pattern as the whole sample model. The Scottish sample is a biased sample due to them being highly educated and from an area where levels of deprivation are low. This is also evident from the types of PA reported, such as golf and gym-based exercise. Second, a participation bias due to the recruitment of volunteers convenience sample could be present. For example, a previous study investigated whether older persons who volunteer to participate in an exercise study differ from non-volunteers (de Souto Barreto et al., 2013). They found that older adults who are inclined to participate in an exercise study are at least partially fitter and healthier than ones who are not inclined to participate, with volunteers being more satisfied with their physical functioning, having a lower level of physical function decline, and higher volumes of PA than non-volunteers (de Souto Barreto et al., 2013). Therefore, care must be taken in generalising the results presented in this Chapter. Future studies should potentially consider assessing the reasons of participants for compliance and attendance in PA studies along with information from people who refuse to participate. Additionally, the current study did not collect data on cognitive functioning. It is well-established that cognitive decline can influence the validity of self-reported data (Herbolsheimer et al., 2018). Thus, future studies should include screening for cognitive impairments, especially if including participants at risk. The participants included in this study were living independently and able to understand verbal and written information, therefore it is less likely that cognitive impairment would have an impact on the results presented. Additionally, future studies should incorporate the investigation of specific self-reported measures (validated questionnaires) to capture important domain-specific activity information.

3.5 Conclusion

In this chapter, differences in 24-h movement behaviours across diverse socioeconomic communities has been highlighted. Movement behaviours have a key role in maintaining health and to the study of healthy ageing. Indeed, it is well-established that reduced levels of PA are an important risk factor for numerous chronic diseases (Gonzales et al., 2017), that SB is an independent predictor of mortality (Patterson et al., 2018), and that appropriate sleep duration is associated with better mental and physical health (Faubel et al., 2009; Stenholm et al., 2010). Therefore, 24-h movement behaviours are fundamental factors influencing the trajectory of decline in physiological function during the aging process. However, evidence concerning the health benefits of movement behaviours has been mainly investigated in HICs with an under-representation of LMICs (Cleland et al., 2019).

Indeed, the presence of barriers to PA in LMICs should be acknowledged with a focus on PA security, ensuring equality in the access to sufficient, safe, and enjoyable spaces for PA. Thus, it is important to include the comparison of diverse socioeconomic settings in movement behaviours research. Indeed, there were differences in 24-h time use allocation of PA, SB, and sleep in the Scottish and South African communities. Scottish older adults engaged in higher intensities PA and spent more time in SB. Conversely, South African participants engaged in higher amount of LPA and longer nocturnal sleep. Understanding the impact of 24-h movement behaviours on health correlates of mobility in older people from diverse socioeconomic communities will inform strategies to maintain and increase PA. Therefore, further study should be investigating different on musculoskeletal health, body composition, and physical functioning of men and women living in these diverse settings.

Chapter 4: Associations of 24-h movement behaviours and musculoskeletal health outcomes in older adult living in Scottish and South African communities

4.1 Introduction

In the previous chapter, we described differences in 24-h movement behaviours in a sample of Scottish and South African older adults. The two cohorts had similar weekly amount of total physical activity (PA), however they displayed significantly different daily time-use compositions. Scottish older adults displayed higher relative time in MVPA and SB compared to the South African counterpart, while South African participants displayed longer sleep duration and greater engagement in LPA. Differences in 24-h movement behaviours, along with differences in health status and obesity prevalence, may lead to different associations between PA patterns and musculoskeletal outcomes in communities living in different socioeconomic settings. Therefore, it is important to investigate associations of movement behaviours with muscle and bone integrity in older adults of similar age living in diverse settings in South Africa and Scotland.

Primary features of ageing include decline in bone and muscle health, which contribute to reduced quality of life and loss of mobility (Curtis et al., 2015). Both bone mineral density (BMD) and muscle mass and strength reach a peak in early adulthood and gradually decrease from approximately the fifth decade of age (Mora & Gilsanz, 2003; Lang et al., 2010). Decreased bone mass and alterations in bone microarchitectural are referred to as osteoporosis, a condition associated with greater fracture risk and reduced mobility (Nielsen et al., 2018). The increased fracture risk caused by osteoporosis has an important impact on public health, due to the association with increased morbidity, reduced physical functioning, and longer hospitalization (Kawalkar, 2015). Sarcopenia is a progressive and generalized skeletal muscle disorder that affects physical functionality and is identified by low muscle strength, along with decreased muscle mass (Cruz-Jentoft et al., 2019). This skeletal muscle disorder is associated with multiple adverse outcomes as comorbidities, physical disability, higher risk of falls, increased hospitalisation, and increased mortality (Senior et al., 2015). The most consistent risk factors for these disorders are obesity (Greco et al, 2015; Wannamethee & Atkins, 2015), smoking habit (Christos et al., 2015; Rom et al., 2012), physical inactivity (Smith & Raab, 1986; Roubenoff, 2000), and poor quality/quantity of sleep (Kobayashi et al., 2012; Lucassen et al., 2017). As such, osteoporosis and sarcopenia are common disorders in older adults affecting their independence, therefore prevention strategies should be a main focus to maintain quality of life with ageing.

Recent studies investigated the crosstalk between muscle and bone tissues due to their shared role in movement activities (Yakabe et al., 2020). This interplay between muscle and bone supports the idea that the mechanical load produced by PA via muscle contraction (muscle-derived force) is the main source for generating strain and shaping bone structure, which helps maintaining BMD and bone integrity with ageing (Patel et al., 2018). However, a lack of adequate mechanical stimuli and physical loading can lead to BMD decline, mediated primarily by an imbalance between increased bone resorption and reduced bone formation (Curtis et al., 2015). Additionally, a recent review highlighted the role of genetic determinants, biochemical factors, circadian rhythm, and nutrition intake (Li et al., 2019) on muscle-bone crosstalk. This evidence supports the need to consider bone, skeletal muscle, and their crosstalk in research with a view to informing movement behaviours guidelines in older adults.

Sedentary behaviour (SB) and reduced engagement in PA are known to have a profound effect on musculoskeletal health. Inactivity has been shown to lead to bone loss (Berard et al., 1997) and loss of muscle mass and strength (Oikawa et al., 2019). Previous bed rest and immobilization studies have shown that a decrease in muscle strength occurs before a decrease in muscle mass (Campbell et al., 2019; Oikawa et al., 2019). Conversely, lifelong physical exercise is associated to better BMD in later years (Micklesfield et al., 2003) and to the preservation of muscle health and physical functioning in older adults (Zampieri et al., 2014). Specifically, allocating more time to higher PA intensities (moderate-to-vigorous PA, MVPA) by reducing time in SB or light PA (LPA) has demonstrated a positive impact on musculoskeletal components, and subsequent reductions in sarcopenia (Sanchez-Sanchez et al., 2019) and osteoporosis (Ng et al., 2020) prevalence in older adults. Increases in leisure time MVPA has been shown to reduce the risk of mobility impairments with advancing age, however, occupational LPA in mid-life may have a detrimental effect on mobility in older age (Hinrichs et al., 2014). Thus, assessing PA and SB is important as low levels of PA are recognized as underlying mechanisms of sarcopenia and osteoporosis (Buford et al., 2010; Jain & Vokes, 2019). Additionally, sleep duration and sleep quality have been associated with an increased risk of osteoporosis (Bevilacqua et al., 2019) and sarcopenia (Rubio-Arias et al., 2019; Pourmotabbed et al., 2019), with previous studies suggesting that insufficient or excessive sleep time might have detrimental effects on musculoskeletal health in adults and older adults (Wang et al., 2018; Chien et al., 2015).

These findings further support the need of a 24-h approach to the investigation of movement behaviours in relation to health outcomes in older adults.

Accordingly, this chapter aims to investigate the associations between objectively measured 24-h movement behaviours and musculoskeletal outcomes (muscle strength, muscle mass, physical performance, and BMD), and their crosstalk, in representative samples of older adults from Scottish and South African communities. Based on previous literature and results from Chapter 3, we hypothesise that higher time in MVPA relative to the other behaviours will be associated with better musculoskeletal outcomes. However, differences in socioeconomic setting, health status, and obesity prevalence will potentially show different associations between movement 24-h behaviours and musculoskeletal outcomes in high and low-income communities.

4.2 Methods

Please refer to Chapter 3 for methods related to participants, anthropometry, and accelerometry data management.

4.2.1 Body composition

Whole and subtotal (whole-body minus head) body composition, including fat-free soft tissue mass (FFSTM), fat mass, and BMD were measured using dual energy x-ray absorptiometry (DXA) (Scotland: iDXA; GE Encore, version 13.40.038, GE Healthcare, Madison, WI, USA; South Africa: DXA; Discovery- W®, version 12.7.3.7, Hologic, Bed-ford, MA, USA) according to standard procedures. Appendicular skeletal muscle mass (ASM), the sum of FFSTM (kg) of both legs and arms, was adjusted for BMI (ASM_{BMI}). BMD was quantified using DXA at the lumbar spine (lumbar vertebrae L1-L4), total hip, and femoral neck. DXA machines were calibrated with phantoms as per manufacturer guidelines each day before starting the testing session. Subjects wore minimal clothing and removed jewellery and metallic objects (were possible) before each scan. Participants undertaking the scan were fasted and with empty bladder.
For whole body measurements, participants were centrally aligned in the scanning area of the DXA machine with a distance of 3 cm from the top line drawn on the surface of the bed to the vertex of the head of the participants, the hands were in a prone position and a distance of 3 cm between the thumbs and the legs was measured. A block was positioned

between participant’s feet in order to maintain a constant distance of 28 cm in each scan (**Figure 16**). All the distances were measured with a metric ruler in each scan.

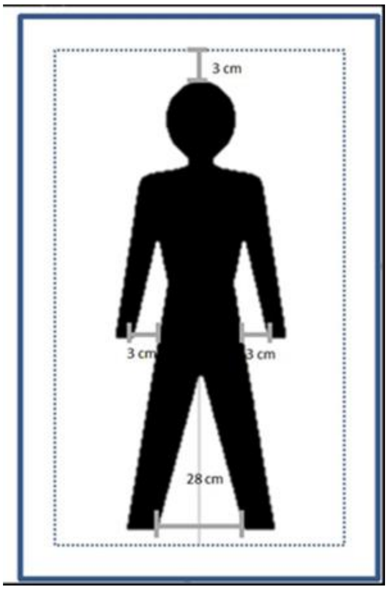


Figure 16. Positioning for whole body measurements with DXA.

For lumbar spine scan, the spine was straight and in the middle of the scan. The participant had arms crossed over the chest and lower limbs were raised on a foam leg block to form a 60° to 90° angle with the tabletop. For dual hips scan, participant's body was in the centre of the scanner table with arms are crossed over the chest. Lower limbs were medially rotated and positioned against a positioning aid.

4.2.2 Grip strength and gait speed

Grip strength (kg) was measured with a hand dynamometer (Scotland: T.K.K.5001, Grip-A, Takei, Tokyo, Japan; South Africa: T.K.K. 5401, Grip-D, Takei, Tokyo, Japan). Measures were taken on both sides, however for sarcopenia assessment the non-dominant side should be considered in the analysis as previous evidence reported greater grip strength in the dominant upper limb (Incel et al., 2002). Participants were in a seated position with their elbow by the side at 90° angle position while holding the dynamometer. The test was repeated three times with a 1-minute rest between each effort. The maximum score achieved was used in the analysis (Sousa-Santos & Amaral, 2017).

4.2.2.1 Gait speed

Gait speed was assessed via a 6-metre walk test. The participants were instructed to walk at a fast pace between two markers set 10 metres apart. Time was measured manually for a 6 metres distance (from 2 metres to 8 metres) to avoid influences of acceleration and deceleration. The mean score ($m.s^{-1}$) from three measurements was recorded (Duncan et al., 2017).

4.2.3 Sarcopenia and bone mineral density cut points

To assess sarcopenia components, we considered grip strength adjusted for BMI (grip $strength_{BMI}$) as our measure of muscle strength, and ASM adjusted for BMI (ASM_{BMI}) as measure of muscle mass, as used by the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project (Studenski et al., 2014). Recommendations for cut points for weakness and low muscle mass included grip $strength_{BMI}$ of <0.1 for men and <0.56 for women, and ASM_{BMI} of <0.789 for men and <0.512 for women, respectively (Studenski et al., 2014). Participants presenting with both weakness and low muscle mass were classified as sarcopenic. The recommended cut point for gait speed is ≤0.8 $m{\cdot}s^{-1}$ (Studenski et al., 2014).

The International Society for Clinical Densitometry (ISCD) guidelines for adults aged ≥50 years were used to determine those with osteopenia (t-score −2.5 to −1) and osteoporosis (t-score < −2.5) at 1 or more bone sites (Looker, 2012; Shuhart et al., 2019).

4.2.4 Statistical analysis

Analysis was conducted using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA) and compositional analysis were conducted using the open-source software Physical Activity CoDa Regression Model (PACRM). Traditional descriptive statistics for musculoskeletal outcomes were stratified according to Scottish and South African groups. The normality of the data was analyzed by the Kolmogorov–Smirnov test combined with Q-Q plots. Descriptive statistics for continuous variables were expressed as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Categorical variables were expressed as frequency and percentage. Regression assumptions were checked, and in all models non-normally distributed dependent variables were transformed with the most appropriate transformation. To investigate the associations between proportions of time spent in the 24-h movement behaviours and musculoskeletal outcomes, compositional linear regression models were then computed separately for both cohorts. For each cohort, 4 compositional linear regression models were performed for each sarcopenia component (grip strength$_{BMI}$, ASM$_{BMI}$ and gait speed) and BMD site (femoral neck BMD, total hip BMD and lumbar spine BMD) as response, via isometric log-ratio (ilr) transformation of the time-use composition (explanatory variables) along with covariates. First, the composition of time spent in sleep, SB, LPA and MVPA was considered. A set of three ilr-coordinates was obtained via sequential binary partition. Model p-values and R^2 coefficients were calculated from unadjusted linear regression models to assess the presence of a statistically significant relationship between time use composition and musculoskeletal components. The first coefficient (γ) and the corresponding p-value for each of the four linear regressions were used to determine if the time spent in a specific behaviour relative to the others was significantly associated with grip strength$_{BMI}$, ASM$_{BMI}$, gait speed, and BMD. We further adjusted BMD models for sarcopenia components, due to the crosstalk between these environments (Yakabe et al., 2020). Outcomes from CoDa analysis should not be interpreted in isolation due to their nature (ratios between behaviours), regression coefficients should be considered relative to the remaining behaviours. To assess the relationship sleep quality derived from the overall score of the PSQI and musculoskeletal outcomes, we performed linear regression analyses to examine the associations between overall PSQI score with muscle strength, muscle mass, and BMD expressed in mean differences with 95% confidence intervals (CI) (Lucassen et al., 2017). Covariates were selected a priori, and all models were adjusted for age, sex, education, smoking status, total physical activity during the week (Lucassen et al., 2017). In addition, we performed logistic regression analyses to estimate odds ratios and 95% CI for low BMD (osteopenia and osteoporosis) and sarcopenia (according to FNIH cut off) associated with the sleep parameter. Statistical significance was set at $p < 0.05$.

4.3. Results

4.3.1. Body composition, bone mineral density and functional measures

Body composition differed between the two cohorts (**Table 12**), with South African older adults having higher fat mass (kg and %) and BMI, and Scottish participants having higher FFSTM and ASM$_{BMI}$. However, unadjusted ASM did not differ between cohorts. Significant differences were found in functional outcomes, with Scottish older adults displaying higher grip strength and grip strength$_{BMI}$ in both men and women, conversely South Africans had a faster gait speed. According to the BMI adjusted FNIH cut-off, the South African group had a higher prevalence of sarcopenia than the Scottish cohort (30.4% vs 2.0%, P<0.01).

Higher rates of osteopenia were found in the Scottish cohort, while higher rates of osteoporosis were found in the South African cohort (**Table 12**).

Table 12. Body composition, functional, and musculoskeletal variables of Scottish and South African cohorts

Variables	Scottish cohort (n=150)	South African cohort (n=138)
Body composition		
Height (cm)	164.7 ±9.2	157.3 ±7.2**
Body mass (kg)	69.0 (60.8-77.3)	79.3 (66.8-93.2)**
BMI (kg/m^2)	25.7 (23.5-28.3)	31.7 (27.8-38.3)**
Underweight (n,%)	2 (1.4)	1 (0.7)
Normal (n,%)		
Overweight (n,%)	57 (38.0)	21 (15.2)
Obese (n,%)	69 (46.0)	32 (23.2)
	22 (14.6)	84 (60.9)
Fat mass (kg)	25.4 ±8.9	34.8 ±14.1**
Fat mass (%)	37.5 (31.6-41.3)	47.2 (40.7-51.8)**
FFSTM (kg)	40.1 (36.3-45.2)	37.2 (33.4-42.3)**
ASM (kg)	17.6 (19.5-27.5)	17.3 (15-20.4)
ASM$_{BMI}$ (kg/m^2)	0.7 (0.6-0.8)	0.5 (0.5-0.6)**
Functional and sarcopenia measures		
Grip strength (kg)	23.0 (19.5-27.5)	20.1 (17.0-23.8)**
Grip strength (kg) men	34.7 (30.0-39.5)	23.8 (19.8-29.0)**
Grip strength (kg) women	21.7 (18.5-24.8)	19.6 (16.8-22.9)**
Grip strength$_{BMI}$ (kg/m^2)	0.9 (0.7-1.2)	0.6 (0.5-0.8)**
Grip strength$_{BMI}$ (kg/m^2) men	1.3 (1.2-1.5)	1.0 (0.8-1.2)**
Grip strength$_{BMI}$ (kg/m^2) women	0.9 (0.7-1.0)	0.6 (0.5-0.7)**
Gait speed (m/s)	1.5 (1.4-1.7)	1.6 (1.4-1.7)*
Sarcopenia (n, %)	3 (2.0)	42 (30.4)**
FNIH muscle weakness (n, %)	15 (10.0)	65 (47.1)**
FNIH low muscle mass (n, %)	7 (4.7)	73 (52.9)**
Bone mineral density		
Femoral neck BMD (g/cm^2)	0.854 ±0.149	0.758 ±0.161
Total hip BMD (g/cm^2)	0.905 ±0.150	0.896 ±0.177
Lumbar spine BMD (g/cm^2)	1.112 ±0.208	0.940 ±0.191
Femoral neck BMD$_{HEIGHT}$ (g/cm^2)	0.515	0.482
Total hip BMD$_{HEIGHT}$ (g/cm^2)	0.547	0.569
Lumbar spine BMD$_{HEIGHT}$ (g/cm^2)	0.672	0.598
Femoral neck T score	-1.3 (-1.7-0.6)	-0.8 (-1.8-0.1)
Total hip T score	-1.1 (-1.7- -0.4)	-0.3 (-1.3-0.7)
Lumbar spine T score	-0.1 (-0.9- - 0.7)	-1.1 (-2.2- 0.1)
Osteopenia (n, %)	105 (70.0)	54 (39.1)
Osteoporosis (n, %)	16 (10.7)	28 (20.3)

*All normally distributed and skewed data are reported as mean ± SD and Median (IQR – 25-75th percentile), respectively. Abbreviations: BMI, Body Mass Index. FFSTM, fat free soft tissue mass. ASM, appendicular skeletal muscle mass. ASMBMI, appendicular skeletal muscle mass adjusted for Body Mass Index. Grip strengthBMI, grip strength adjusted for Body Mass Index. FNIH, Foundation for the National Institutes of Health. BMD, bone mineral density. P values represent a significant difference between groups. Parametric and non-parametric (Mann-Whitney U) independent t-tests were conducted on normally distributed and skewed data, respectively. Chi-square was used to determine differences in frequency of each variable between Scottish and South African cohorts. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

4.3.2. Relationship between 24-h time use composition and musculoskeletal health in Scottish and South African older adults

Compositional linear regression models in relation to sarcopenia components and BMD are shown in **Table 13**. In the Scottish cohort, higher relative time spent in MVPA was positively associated with higher grip strength$_{BMI}$ and ASM$_{BMI}$ (**Table 13**). No associations between a specific movement behaviours and BMD were found. When adjusting the model for grip strength, ASM, and/or gait speed (**Table 14**), no association between 24-h time use composition and BMD outcomes were found. However, when adjusting for only grip strength, the relative time spent in SB was negatively associated with femoral neck BMD. In both cohorts, the overall 24-hour time use composition accounted for a similar proportion of the variance for grip strength and ASM (**Table 13**). Conversely, in the South African sample, more time spent in MVPA relative to the other behaviours was associated with higher gait speed and total hip BMD. Indeed, in the South African cohort only, a significant association between movement behaviours and gait speed was reported. Time use composition explained almost 35% of the variance in gait speed in this cohort, with MVPA significantly dictating the association. When adjusting for grip strength, ASM and/or gait speed, MVPA remained positively associated with total hip BMD in the South African cohort (**Table 15**). Therefore, the relationship between relative time spent in MVPA and total hip BMD was independent of sarcopenia components. In the South African sample, when additionally adjusting the model for grip strength and ASM (**Table 15**) a positive association between relative time in MVPA and femoral neck BMD was found, however when gait speed was included as a covariate, the positive association with femoral neck BMD was no longer significant. The overall 24-hour composition explained a similar amount of variance for femoral neck BMD in both cohorts (±7%). However, an association between overall 24-hour composition and hip total BMD was only reported the South African cohort and accounted for ±10% of the variance.

Table 13. Compositional linear regression for the associations between movement behaviours and musculoskeletal outcomes

Variables	γ sleep	γ SB	γ LPA	γ MVPA	Model R^2
Scottish cohort					
Grip strength$_{BMI}$ (kg/m^2)	0.07	-0.12	-0.05	**0.10****	**0.12****
ASM$_{BMI}$ (kg/m^2)	-0.04	-0.02	0.01	**0.05****	**0.12****
Gait speed (m/s)	0.10	-0.09	-0.01	0.01	0.05
Log femoral neck BMD (g/cm^2)	0.13	-0.12	-0.04	0.02	**0.07***
Log hip total BMD (g/cm^2)	-0.02	-0.03	0.04	0.01	0.01
Log lumbar spine BMD (g/cm^2)	-0.04	0.03	0.03	-0.01	0.01
South African cohort					
Grip strength$_{BMI}$ (kg/m^2)	0.11	-0.15	0.02	0.01	**0.11****
ASM$_{BMI}$ (kg/m^2)	0.04	-0.06	0.02	0.01	**0.20****
Log Gait speed (m/s)	-0.04	-0.01	0.02	**0.03****	**0.35****
Femoral neck BMD (g/cm^2)	-0.06	0.02	0.02	0.02	**0.07***
Total hip BMD (g/cm^2)	-0.02	-0.01	0.01	**0.03***	**0.10****
Lumbar spine BMD (g/cm^2)	-0.01	-0.04	0.07	-0.02	0.01

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Regression coefficients and corresponding p-values were adjusted for age, sex, education, and smoking status. Gait speed and bone mineral density (BMD) variables were further adjusted for Body Mass Index (BMI). Regression coefficients and corresponding p-values for South African sample were additionally adjusted for diabetes and human immunodeficiency virus (HIV) prevalence. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

Table 14. Compositional linear regression model for Scottish cohort between bone mineral density variables and movement behaviours considering bone-muscle crossktalk

Variables	γ sleep	γ SB	γ LPA	γ MVPA
Model 1: additionally adjusted for grip strength				
Log femoral neck BMD (g/cm^2)	0.11	**-0.11***	-0.05	0.03
Log hip total BMD (g/cm^2)	-0.03	-0.02	0.04	0.01
Log lumbar spine BMD (g/cm^2)	-0.04	0.03	0.02	-0.01
Model 2: additionally adjusted for ASM				
Log femoral neck BMD (g/cm^2)	0.13	-0.11	-0.05	0.02
Log hip total BMD (g/cm^2)	-0.03	-0.012	0.04	0.01
Log lumbar spine BMD (g/cm^2)	-0.04	0.03	0.02	-0.01
Model 3: additionally adjusted for gait speed				
Log femoral neck BMD(g/cm^2)	0.13	-0.11	-0.04	0.02
Log hip total BMD (g/cm^2)	-0.03	-0.02	0.04	0.01
Log lumbar spine BMD (g/cm^2)	-0.01	0.03	0.02	-0.01
Model 4: additionally adjusted for grip strength + ASM + gait speed				
Log femoral neck BMD (g/cm^2)	0.13	-0.01	-0.01	0.02
Log hip total BMD (g/cm^2)	-0.03	-0.02	0.04	0.01
Log lumbar spine BMD (g/cm^2)	-0.38	0.03	0.02	-0.01

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Regression coefficients and corresponding p-values were adjusted for age, gender, education, smoking status, and Body Mass Index (BMI). Model 1, 2 and 3 were respectively additionally adjusted for grip strength, appendicular skeletal muscle mass and gait speed. Model 4 was additionally adjusted for all sarcopenia components. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

Table 15. Compositional linear regression model for South African cohort between bone mineral density variables and movement behaviours considering bone-muscle crossktalk				
Variables	**γ sleep**	**γ SB**	**γ LPA**	**γ MVPA**
Model 1: additionally adjusted for grip strength				
Femoral neck BMD (g/cm^2)	-0.08	0.02	0.04	**0.02***
Hip total BMD (g/cm^2)	-0.05	0.01	0.02	**0.03****
Lumbar spine BMD (g/cm^2)	-0.03	-0.03	0.06	-0.01
Model 2: additionally adjusted for ASM				
Femoral neck BMD (g/cm^2)	-0.09	0.01	0.05	**0.02***
Hip total BMD (g/cm^2)	-0.05	-0.01	0.02	**0.04****
Lumbar spine BMD (g/cm^2)	-0.04	-0.04	0.08	-0.01
Model 3: additionally adjusted for gait speed				
Femoral neck BMD (g/cm^2)	-0.08	0.01	0.04	0.02
Hip total BMD (g/cm^2)	-0.04	-0.01	0.01	**0.03***
Lumbar spine BMD (g/cm^2)	-0.02	-0.04	0.07	-0.01
Model 4: additionally adjusted for grip strength + ASM + gait speed				
Femoral neck BMD (g/cm^2)	-0.09	0.02	0.04	0.02
Hip total BMD (g/cm^2)	-0.04	0.01	0.04	**0.03***
Lumbar spine BMD (g/cm^2)	-0.04	-0.03	0.07	-0.01
*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Regression coefficients and corresponding p-values were adjusted for age, gender, education, smoking status, Body Mass Index (BMI), diabetes, and human immunodeficiency virus (HIV) prevalence. Model 1, 2 and 3 were respectively additionally adjusted for grip strength, appendicular skeletal muscle mass, and gait speed. Model 4 was additionally adjusted for all sarcopenia components. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*				

4.3.3 Sensitivity analysis

In the compositional regression models for the South African sample, we adjusted for the two main diseases that were different in the cohorts (HIV and diabetes). Diabetes and HIV were not significant contributors in these models. Results of the sensitivity analysis on the subsample of South African participants (excluding diabetes and diabetes + HIV) are presented in **Table 16**. Statistical significance from these models follows the same pattern as the models presented in **Table 16**.

Table 16. Subsample analysis for compositional linear regression for the associations between movement behaviours and musculoskeletal outcomes					
Variables	**γ sleep**	**γ SB**	**γ LPA**	**γ MVPA**	**Model R^2**
South African cohort (no diabetes, n=107)					
Grip $strength_{BMI}$ (kg/m^2)	0.09	-0.19	0.09	0.01	**0.15***
ASM_{BMI} (kg/m^2)	-0.01	-0.02	0.01	0.01	**0.22****
Log Gait speed (m/s)	-0.04	0.01	0.01	**0.03****	**0.28****
Femoral neck BMD (g/cm^2)	-0.06	-0.01	0.04	0.03	**0.12****
Total hip BMD (g/cm^2)	-0.01	-0.05	0.02	**0.04***	**0.14****
Lumbar spine BMD (g/cm^2)	0.01	-0.06	0.06	-0.01	0.02
South African cohort (no diabetes and no HIV, n=98)					
Grip $strength_{BMI}$ (kg/m^2)	0.08	-0.20	0.11	0.01	**0.14****

ASM_{BMI} (kg/m^2)	-0.0	0.01	0.01	0.01	**0.22****
Log Gait speed (m/s)	-0.06	0.03	0.02	**0.02****	**0.26****
Femoral neck BMD (g/cm^2)	-0.14	0.03	0.08	0.02	**0.11***
Total hip BMD (g/cm^2)	-0.10	0.01	0.06	**0.03***	**0.12****
Lumbar spine BMD (g/cm^2)	-0.05	-0.02	0.07	-0.01	0.01

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Regression coefficients and corresponding p-values were adjusted for age, sex, education, and smoking status. Gait speed and bone mineral density (BMD) variables were further adjusted for Body Mass Index (BMI). The first model was additionally adjusted for HIV prevalence. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

4.3.3. Association of sleep quality with BMD, muscle strength, and muscle mass in Scottish and South African older adults

In the Scottish cohort, grip strength was the only musculoskeletal outcome significantly different between participants with good and poor quality of sleep considering the PSQI overall score. Specifically, the significant result was driven by difference of sleep quality in women (**Figure 17**). Conversely, no significant differences were found in the South African sample across good and poor sleep quality groups. **Table 17** and **18** show the mean differences in grip $strength_{BMI}$, ASM_{BMI}, and BMD at the femoral neck, hip, and lumbar spine associated with one unit change in the PSQI overall score. Grip strength was significantly associated with sleep quality parameter in the Scottish cohort, both in the crude model and after adjustment for potential confounding factors. Specifically, with each unit increase in PSQI score (higher values represent poorer sleep quality), grip $strength_{BMI}$ was 0.010 kg/m^2 and 0.028 kg/m^2 reduced, respectively in the Scottish cohort. Measures of BMD at each site in Scottish and South African participants were weakly associated with sleep quality parameters.

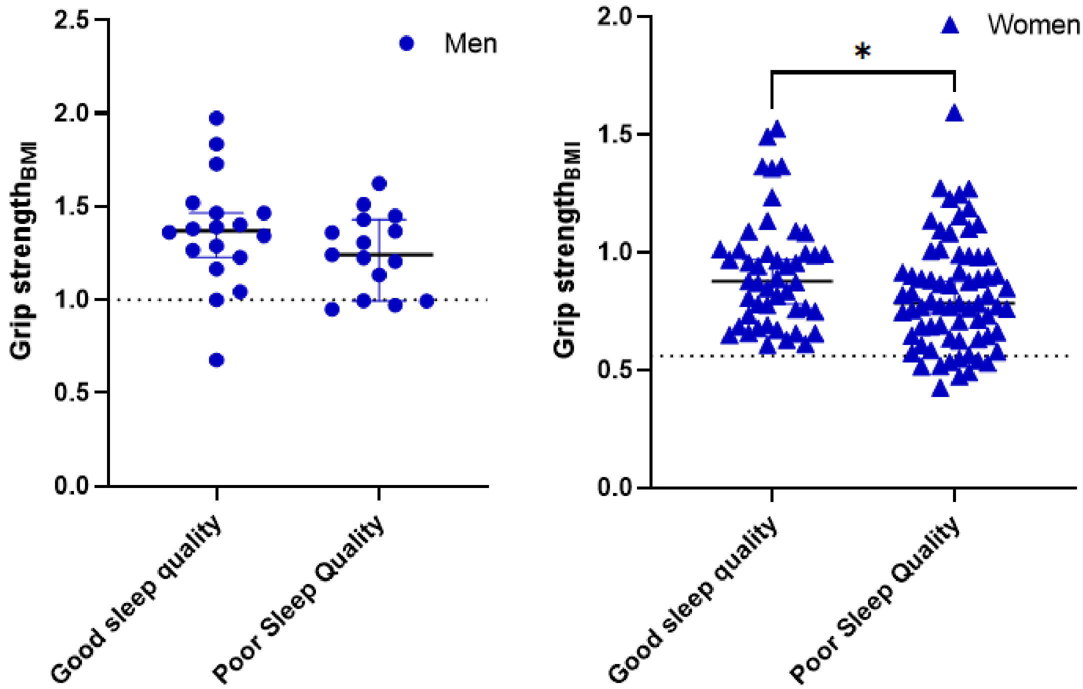


Figure 17. Grip strengthBMI value according for men and women to sleep quality score (poor sleep quality defined as overall score >5). Statistically significant results p<0.05.*

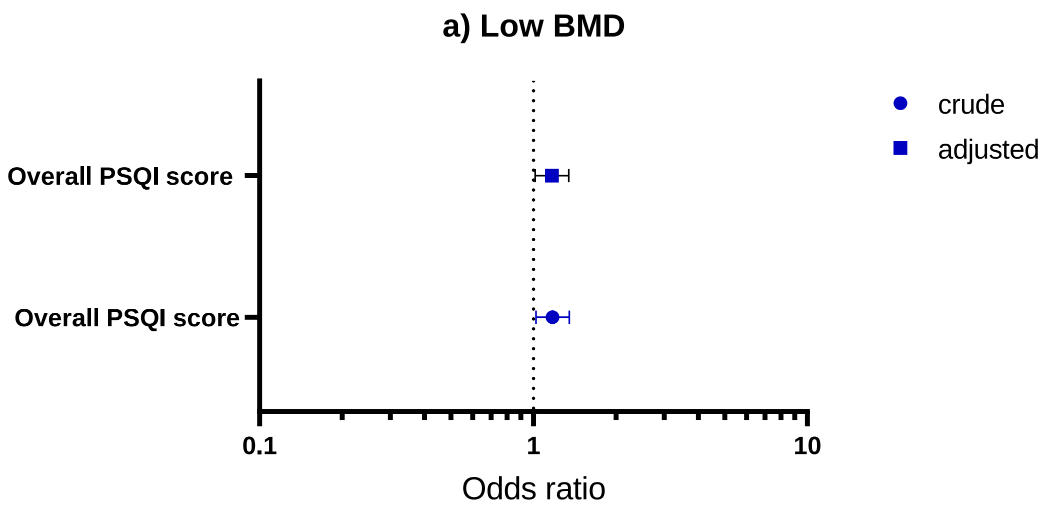
Table 17. Difference (95% CI) in grip strength, ASM, femoral neck BMD, hip total BMD, and lumbar spine BMD per unit change of sleep parameter in the Scottish cohort

	Grip strength$_{BMI}$ (kg/m^2)	ASM$_{BMI}$	Femoral neck BMD (g/cm^2)	Hip total BMD (g/cm^2)	Lumbar spine BMD (g/cm^2)
Crude model (age, sex)					
Overall PSQI score	-0.01 (-0.02- - 0.01)	0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.01)	-0.01 (-0.01 – 0.01)	0.01 (-0.01 – 0.01)
Adjusted model (age, sex, education, smoking, total PA)					
Overall PSQI score	-0.01 (-0.02 – 0.01)	0.01 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)

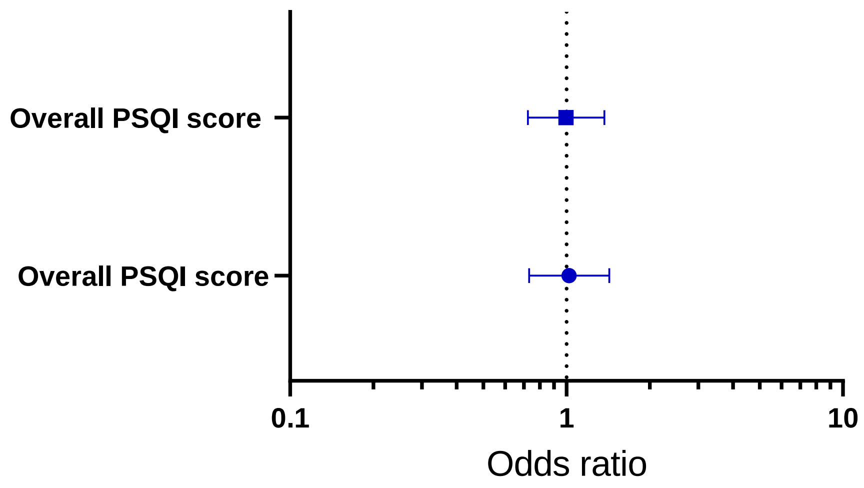
Crude model: age, sex; adjusted model: age, sex, education, smoking status, total weekly physical activity. Bone mineral density outcomes were additionally adjusted for body mass index. Abbreviations: BMI, body mass index. BMD, bone mineral density. PSQI, Pittsburgh Sleep Quality Index. PA, physical activity.

Table 18. Difference (95% CI) in grip strength, ASM, femoral neck BMD, hip total BMD, and lumbar spine BMD per unit change of sleep parameter in the South African cohort					
	Grip $strength_{BMI}$ (kg/m^2)	ASM_{BMI}	Femoral neck BMD (g/cm^2)	Hip total BMD (g/cm^2)	Lumbar spine BMD (g/cm^2)
Crude model (age, sex)					
Overall PSQI score	0.01 (-0.01-0.01)	0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)
Adjusted model (age, sex, education, smoking, total PA)					
Overall PSQI score	0.01 (-0.01-0.01)	0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)	-0.01 (-0.01-0.01)
Crude model: age, sex; adjusted model: age, sex, education, smoking status, total weekly physical activity. Bone mineral density outcomes were additionally adjusted for body mass index. Abbreviations: BMI, body mass index. BMD, bone mineral density. PSQI, Pittsburgh Sleep Quality Index. PA, physical activity.					

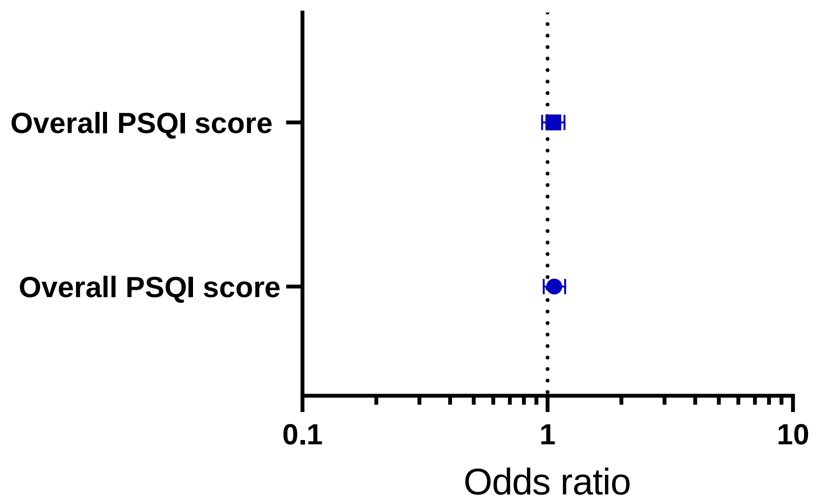
In the Scottish cohort, only 2% of the participants were classified as sarcopenic (**Figure 18b**), which precluded reliable estimation of the relationship between sleep quality and sarcopenia. However, overall PSQI score was associated with higher odds of osteopenia and osteoporosis (low BMD). In the Scottish cohort each unit increase in PSQI score was associated with 17% increased risk of low BMD (OR 1.17, 1.01-1.35) (**Figure 18a**). Conversely, overall PSQI score did not affect the risk of osteopenia or sarcopenia in the South African sample (**Figure 18d**).



b) Sarcopenia



c) Low BMD



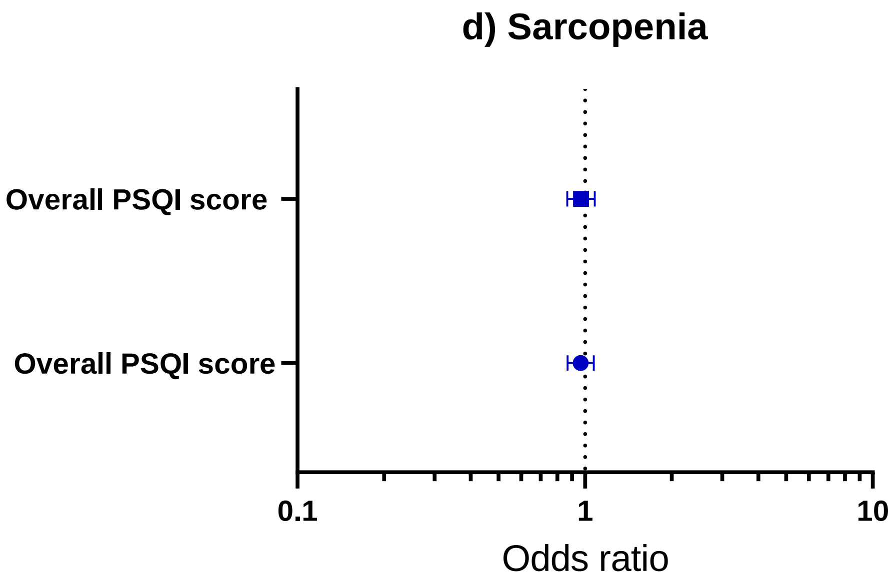


Figure 18. Odd ratios (95% CI) per unit change of overall PSQI score and self-rated sleep quality for low bone mineral density in the Scottish sample (a), sarcopenia in the Scottish sample (b), for low bone mineral density in the South African sample (c) and sarcopenia in the South African sample (d). Abbreviations: BMD, bone mineral density. PSQI, Pittsburgh Sleep Quality Index. Low bone mineral density defined as t-score<-1.5; sarcopenia according to FNIH cut off. Crude: age, sex; adjusted: age, sex, education, smoking status, total weekly PA models are shown.

4.4. Discussion

In this chapter, we examined associations of 24-h movement behaviours with various measures of musculoskeletal health in Scottish and South African communities. We found positive associations between relative time spent in MVPA and sarcopenia components and BMD, but these differed between the two cohorts. Specifically, higher MVPA time relative to the other behaviours was associated with higher values of ASM_{BMI} and grip $strength_{BMI}$ in the Scottish cohort, and higher gait speed and total hip BMD in the South African cohort. Our results suggest that interventions targeted at older adults should consider the importance of engaging in higher intensities of PA patterns irrespective of the sociodemographic profile. However, associations between MVPA and components of musculoskeletal health were different between socioeconomic settings.

4.4.1 Scottish sample

Our finding of a beneficial association in the Scottish sample between MVPA, muscle mass, and muscle strength confirms the importance of PA intensity on musculoskeletal health in older adults. Specifically, greater relative time spent in MVPA was associated with better grip strength and ASM outcomes. However, sarcopenia prevalence in this cohort was quite low (2%), with 10% of participants displaying muscle weakness (according to FNIH cut off). This finding is in agreement with a previous study investigating prevalence of muscle weakness (with FNIH cut off) in community-dwelling older adults in the UK (Pinedo-Villanueva et al., 2019). The prevalence of muscle weakness reported in the Hertfordshire Cohort Study (HCS) was 11%. This finding is slightly higher compared to the prevalence reported in our study, this is probably due to the higher age range included in the HCS (71–80 years), as previous evidence suggested increased risk of sarcopenia with advancing age (Mitchell et al., 2012; Hughes et al., 2001). Additionally, the low sarcopenia prevalence in this study could be explained by the presence of a selection bias with participants volunteering having better physical function and higher volumes of MVPA (de Souto Barreto et al., 2013) than non-volunteers. Also, prevalence of sarcopenia can vary according to which diagnostic criteria are applied to the study sample (Mayhew et al., 2019).

Our observations of positive effects of MVPA on sarcopenia components agree with previous evidence involving older adults from HICs (Sanchez-Sanchez et al., 2019; Marcos-Pardo et al., 2021). Indeed, regular weekly MVPA has been found to reduce sarcopenia risk and to be consistently associated with reduced incidence of lower values of grip strength and ASM in a Swedish sample of 70-year-olds (Scott et al., 2020). Another previous study highlighted a reduction in sarcopenia prevalence by displacing 15 min of either SB or LPA in favor of MVPA in Spanish older adults (Sanchez-Sanchez et al., 2019). Our study supports previous research demonstrating that objectively measured MVPA is associated with individual components of sarcopenia (Foong et al., 2016). Recent studies reported a positive association of greater amounts of PA with muscle mass in older adults (Distefano & Goodpaster, 2018), however conflicting findings are present (Gaba et al., 2021). Considering associations of PA and functional measures of sarcopenia, existing evidence, in agreement with our findings, supports the beneficial effect of PA on performance and maintenance of physical function (Fielding et al., 2017). However, most of the previous studies mentioned did not consider effects of whole 24-h spectrum on movement behaviours. Indeed, the novelty of our findings is in the consideration of the time spent across the entire 24-h day and the co-dependence between behaviours.

In the Scottish sample, SB was negatively associated with neck femur BMD and this association was mediated by grip strength. Our finding supports the idea that reduced mechanical forces leads to decreased bone strength (Huiskes et al., 2000) with a detrimental effect on general bone health. A review explored effects of SB on bone integrity in young adults and children whereupon a moderate negative association between SB and BMD was found in the lower limbs (Keodijk et al., 2017). Recently, a systematic review on

the association between SB and BMD in older adults aged 65+ has been published (McMichan et al., 2021). In the studies included in the review, SB and sitting time displayed negative associations when femoral neck BMD was considered (McMichan et al., 2021). However, inconsistent findings were reported across genders and the studies included in the review considered only healthy adults. This highlights the need of including older adults with differences in health status and supports the relevance of comparing populations from diverse socioeconomic settings. Previous data have shown that time spent sitting is negatively associated with hip BMD (Chastin et al., 2014), and reported a negative impact of SB, independently of PA, on bone integrity. Our finding further expands this idea by demonstrating that it is the time spent in SB relative to the other 24-h movement behaviours which drive the association with BMD. Additionally, we have shown that the association between SB and femoral neck BMD was mediated by grip strength in Scottish older adults. Grip strength is well recognized as a proxy for PA (Kim et al., 2017) and is consistently associated with BMD across sites (Bohannon, 2019; Luo et al., 2020). Additionally, grip strength was also a significant contributor to the model, further supporting the idea that the association between BMD and SB is mediated by muscle strength. This finding reinforces the idea of the crosstalk between muscle and bone, suggesting a shared pathological process in older adults (He et al., 2020). Therefore, future studies should include the investigation of the muscle and bone link.

4.4.2 South African sample

In the South African cohort, the relative time spent in MVPA was positively associated with gait speed. Additionally, in the South African sample sarcopenia prevalence across both sexes was 30%, with a greater proportion of women (29%) presenting low values of sarcopenia determinants (muscle mass, muscle strength, and gait speed). Our finding agrees with previous evidence investigating prevalence of sarcopenia in South African and African older adults. Indeed, using FNIH definitions sarcopenia prevalence ranged from 28% (Mendham et al., 2021) and 39% (Kruger et al., 2015) in South African older women to 45% of Gambians women (Zengin et al., 2018). Importantly, sarcopenia has been associated with reduced quality of life in older adults (Tsekoura et al., 2017). Additionally, a recent review on the association of sarcopenia and adverse medical conditions in older adults highlighted that the skeletal muscle disorder was associated with premature mortality, disability, and falls (Marzetti et al., 2017). Due to the high prevalence of sarcopenia and the evident link with adverse health outcomes, future research should further explore modifiable risk factors to inform interventions in LMICs.

The present chapter shows associations between movement behaviours and hip BMD in the South African cohort. Our results agree with previous studies reporting greater hip and femoral neck BMD with the engagement in habitual PA and MVPA (Langsetmo et al., 2012). The reason for the beneficial effect of PA on hip BMD could be related to greater cortical bone in femoral neck and total hip components, which is more susceptible to mechanical loading and absorption of ground reaction forces (Onambele-Pearson et al., 2019; Rodriguez-Gomez et al., 2018). Alternatively, the density of bones at the lumbar spine, due to the predominance of trabecular bone, is more sensitive to the metabolic milieu rather than mechanical loading (Chantler et al., 2012). Total hip BMD was positively associated with relative time in MVPA in the South African cohort. Most of the PA performed in the South African group is low intensity walking for transport (Guthold et al., 2011), leading to a greater influence and protective effect of PA on hip bones. Additionally, when adjusting our models for sarcopenia components in the South African cohort, the association between MVPA and total hip BMD remained significant, highlighting the independence of this relationship from muscular and functional factors. Despite this association, in our study, the prevalence of osteoporosis was still high in the South African cohort. This could be explained by the large proportion of South African older adults not meeting PA guidelines (in the form of MVPA engagement), which can lead to a decline in bone integrity; however, other risk factors for osteoporosis, such as nutrition, should be acknowledged. Indeed, a recent study highlighted that 40% of South African women living in a in a low-income, urban community were considered to be moderately or severely food insecure (Odunitan-Wayas et al., 2021). Thus, the importance of meeting PA recommendations should be reinforced in older adults from LMICs. However, the ideal amount of MVPA to prevent a decline in BMD is still poorly defined as the dose–response association between MVPA and BMD is not fully understood (Shad et al., 2016). Indeed, multiple exercise types (involving balance, endurance, resistance, and functional exercise) appear to be more effective for maintaining bone health and reducing the risk of fracture (Pinheiro et al., 2020). Future longitudinal and intervention studies are required to address this research gap.

4.4.3 Comparison of Scottish and South African samples

Although the musculoskeletal outcomes positively associated with MVPA are different between the cohorts, the findings overall suggest that higher volumes of high-intensity PA appear to be associated with favourable results on functional outcomes including muscle strength, muscle mass, and physical functioning. However, different associations between movement 24-h behaviours and musculoskeletal outcomes were found across socioeconomic settings. Differences in functional outcomes between the two cohorts could be due to differences in modalities and activities to achieve higher PA intensities. Scottish older adults engage in MVPA mostly for recreational and exercise purposes with gym-based exercise and sports (involving also upper body usage) (Strain et al., 2016), potentially resulting in greater values of grip strength and muscle mass. In contrast, the main contributors to PA in the South African cohort are active travel and occupational duties (Strain et al., 2020; Gradidge et al., 2014), leading to greater engagement of lower body functionality. Consequently, our results confirm the importance of MVPA for muscular health in older adults when considered relative to other movement behaviours. However, the influence of PA domains (leisure and occupational) among groups of older adults in different socio-economic settings should be considered.

Interestingly, when considering the whole 24-h spectrum in the Scottish cohort, SB was the only behaviour associated with BMD and this was only observed after adjusting for grip strength. Conversely, higher relative daily time spent in MVPA was associated with better hip total bone health outcomes in the South African cohort. However, when muscle mass and muscle strength were considered in the model, femoral neck BMD was also positively associated with relative time spent in MVPA. This association further reinforces the presence of a muscle-bone unit, suggesting that future interventions should target engagement in resistance training (Fragala et al., 2019) involving also upper body activities in older adults in both HICs and LMICs. Indeed, previous evidence recommends resistance training as a promising low-cost and safe intervention strategy for the preservation of musculoskeletal health (Beck et al., 2017). Although mechanisms via which exercise improves bone health are not fully understood, it seems that resistance training produces mechanical stress exceeding the mechanical load encountered during daily activities (Frost, 1988), leading to an enhanced osteoblast activity (Palombaro et al., 2013; Fragala et al., 2019). Therefore, future studies should include the assessment of resistance training in older adults.

In the Scottish cohort, a decline in sleep quality (PSQI overall score) measures was associated with an increased risk of osteopenia and osteoporosis. This finding agrees with previous evidence on the influence of quality of sleep on altered bone parameters in a cohort of older community-dwelling adults in the UK (Bevilacqua et al., 2020). The relationship between sleep quality and reduced values of BMD is in accordance with existing literature, that has reported associations between sleep quality and osteoporosis (Sasaki et al., 2016) and risk of fractures (Holmberg et al., 2006). These associations have been previously explained as a consequence of disruptions in the circadian clock leading to abnormal bone metabolism and osteoporosis (Song et al., 2018). Additionally, Scottish older women with good sleep quality (defined as an overall PSQI score<5) displayed higher values of grip strength compared to individuals with poor sleep quality. Sleep patterns change with advancing age, with alteration in sleep quality. Muscle strength decline with ageing (Keller & Engelhardt, 2013) and is currently the most reliable marker of muscle function (Legrand et al., 2014). The presence of an interaction between these components of health, could support targeting sleep habits as modifiable parameters to improve muscle health.

Our data suggest that MVPA was associated with better musculoskeletal health in both cohorts; however, this poses a challenge as a low percentage of South African older adults met PA guidelines as indicated by their lower engagement in higher PA intensities or MVPA. A previous study (Smit et al., 2016) showed that barriers to MVPA in a low-income South African setting included the perception of poor facilities and safety issues in the neighborhood, making it harder to engage in recreational MVPA. Inequalities in accessing opportunities to engage in leisure PA occur in most LMICs, with poor and overcrowded environments, lack of adequate facilities, and safety representing major barriers to PA (Lambert et al., 2020). Thus, when targeting engagement in PA in LMICs, we need to acknowledge the associated challenges, with the potential aim of removing these barriers. Conversely, many Scottish older adults were engaging in appropriate amount of PA according to WHO recommendations on movement behaviours. However, they also spent ≈ 10 h of the day in SB, and in line with the most recent recommendations by the WHO, this may have detrimental effects on increased risk of developing a chronic disease and mortality (Dempsey et al., 2020). To sustain beneficial effects that PA has on different health outcomes with ageing, we should support older adults to maintain PA levels while reducing SB, particularly during the COVID-19 pandemic.

There are also differences across the two samples which could influence the results presented in this Chapter. First, inadequate energy and protein intake is an important factor for sarcopenia and osteoporosis (Hanach et al., 2019; Munoz-Garach, et al., 2020). Indeed, previous evidence showed that insufficient protein consumption has been associated with reduction in muscle mass and poor physical function in older adults (Baum & Wolfe, 2015). A previous study on older South African women demonstrated that low muscle mass was relatively prevalent (22%) and was associated with low dietary protein (Mendham et al., 2019). Additionally, dietary protein intake is essential for bone health (Munoz-Garach, et al., 2020) with proteins integrated in the bone organic matrix and affecting grow factor hormones important for bone formation (Tsagari, 2020). A recent systematic review and meta-analysis reported that a higher protein intake than the general dietary recommendations (0.8 g/kg body weight/day) is associated with a higher BMD and it is beneficial in in attenuating age-related bone loss and reducing hip fracture risk in older subjects (Groenendijk et al., 2019). Diet and food security are relevant behaviours when describing a population in a LMIC. The African context presents the co-existence of undernutrition and overweight/obesity (Ameye & Swinnen, 2019). Specifically, South Africa has the highest prevalence of overweight and obesity in sub-Saharan Africa occurring simultaneously with 64% of households experiencing food insecurity (Haysom et al., 2017). Secondly, it is well-established that vitamin D deficiency leads to decreased calcium absorption and ultimately to bone demineralization (Lips, 2001). Previous evidence identified participants from Scotland as the most likely to suffer from vitamin D deficiency within British population (Hypponen & Power, 2007). Therefore, future studies aiming to describe populations from different countries and socioeconomic background should include measures of dietary patterns, food security, and vitamin D levels. There are factors to account for when considering the results from this chapter. First, different machines were used for multiple measures (whole body composition, bone measures, and grip strength), which meant that a direct comparison between the Scottish and South African participants for multiple measures was not feasible. Regardless, this does not preclude the comparison of associations between 24-h movement behaviours and musculoskeletal outcomes. Additionally, we measured sleep quality with self-reported information from questionnaire, thus future studies should include objective measurements of sleep quality with the use of wrist-worn actigraphy. Lastly, we did not consider the role of habitual strength training, as we focused on aerobic physical activity and future studies should also consider the potential mode specific training effects on musculoskeletal determinants.

4.5. Conclusion

We highlighted the importance of the relative time spent in MVPA across the whole day on musculoskeletal health in older adults in both a LMIC and a HIC. Higher daily time allocations to MVPA relative to other behaviours were associated with better musculoskeletal and bone health. While the beneficial effect of MVPA in isolation on muscle and bone integrity is already known, recent evidence argued whether this positive impact remained when the whole day is considered. Our findings confirm the protective role of MVPA on muscle mass, muscle strength, physical functioning, and BMD. Specifically, in the Scottish group, higher time spent in MVPA relative to the other behaviours was associated with greater muscle mass and muscle strength, while relative time spent in SB, mediated by muscle strength, was the main contributor to lower BMD. Thus, national plans and policymakers should support older adults in HICs in maintaining appropriate volume and intensity of PA and reducing SB with ageing. Conversely, in the South African setting, higher relative time in MVPA had a positive effect on physical functioning and BMD. However, the presence of barriers to PA in LMICs should be acknowledged with a focus on PA security, ensuring equality in the access to sufficient, safe, and enjoyable spaces for PA. Thus, an integrated approach including the promotion of high-intensity PA and equality in PA access is needed. Accordingly, future interventions should target the knowledge around the importance of engaging in higher PA intensities with ageing for musculoskeletal health acknowledging the challenges in different socio-economic settings.

Chapter 5: Associations of 24-h movement behaviours, adiposity, blood pressure, and physical functioning in older adults living in Scottish and South African communities

5.1. Introduction

In the previous Chapter, the impact of 24-h movement behaviours on musculoskeletal health in older adults was examined. Loss of skeletal muscle mass and strength (sarcopenia) is identified as a key public health issue in both HICs and LMICs as it results in disability, reduced mobility, loss of independence, and reduced quality of life in older adults (Janssen, 2006; Alva et al., 2013; Woo et al., 2016). However, age-related loss of muscle mass is often accompanied by increased fat mass with a central redistribution (Beaufrere & Morio, 2000) and infiltration of fat into skeletal muscles (Marcus et al., 2010). The coexistence of diminished muscle strength and muscle mass along with increased fat mass is referred to as sarcopenic obesity and it is associated with impaired mobility and/or greater cardiometabolic risk (Parr et al., 2013). Higher fat mass is associated with greater functional disability (Bouchard et al., 2009) and loss of physical function (Visser et al., 2005) in older adults. Consequently, the concomitant presence of ageing and obesity may accelerate skeletal muscle catabolism, decline in physical function, and inflammation which contributes towards anabolic resistance (Welch et al., 2020; Kalyani et al., 2014). Therefore, understanding how 24-h movement behaviours affect adiposity outcomes and physical functioning is an important target to enhance older adults' health with the aim to decrease accelerated muscle loss and fat deposition as a result of inactivity.

Obesity, defined as having a body mass index (BMI) of 30 kg/m² or greater (World Health Organisation, 1998), has been linked to a range of chronic diseases and negative cardiometabolic outcomes (Tay et al., 2019). Additionally, both in Scotland and South Africa, obesity prevalence is higher in older age groups compared to young individuals (Puoane et al., 2012; Scottish Health Survey, 2019). The ageing population in LMICs across Africa is increasing alongside the burden of obesity and non-communicable diseases (Mudie et al., 2019). Obesity levels in South Africa are among the highest in sub-Saharan Africa (Agyemang et al., 2016, Micklesfield et al., 2013), with a prevalence of 11% and 41%, respectively, for men and women over the age of 15 with the greatest contribution from urban areas (Puoane et al., 2012). However, the prevalence of obesity and adiposity is also growing with ageing in HICs (Doak et al., 2012; Gába & Přidalová, 2014). Specifically, 37% of Scottish older adults aged 65-74 were classified as individuals with obesity in 2019 (33% and 42% of women and men, respectively) (Scottish Health Survey, 2019). Older adults are at high risk of abdominal obesity (Cho et al., 2018) and unfavourable changes in body composition (Koster & Schaap, 2015). Additionally, in the ageing population, the combination of physical inactivity and increased dietary energy intake leads to a relevant exposure to risk factors for numerous co-morbidities (Parr et al., 2013). For example, with sarcopenic obesity, older adults are not only losing skeletal muscle mass but concomitantly gaining fat mass (Wannamethee et al., 2007). High fat mass can further exacerbate sarcopenia as lipid accumulation affects the skeletal muscle by reducing protein synthesis (Masgrau et al., 2012). Specifically, high adiposity could compromise muscle quality (Scott et al., 2018) and increase hip fracture risk (Li et al., 2017). Indeed, previous evidence highlighted the positive association of lean mass (and not fat mass) with bone mineral density (Leslie et al., 2014). Additionally, previous studies reported that high fat mass is associated with poor balance responses in older people and increase the risk of falls (Teasdale et al., 2007; Mainenti et al., 2011). However, existing evidence is limited by using BMI as a proxy for obesity. BMI has been shown to poorly indicate adiposity and it does not distinguish between fat mass and lean mass (Nuttall, 2015). Previous studies demonstrated the role of fat mass as the main cause of obesity-related health risks (Dixon, 2010), while lean mass is inversely associated with mortality risk (Wang et al., 2019). Thus, in this chapter, we aim to include more reliable markers of adiposity (waist circumference and fat mass) in order to assess the associations of these measures with 24-h movement behaviours in diverse socioeconomic settings. Additionally, evidence regarding the interaction effects of 24-h movement behaviours on adiposity outcomes is mixed. To our knowledge, a restricted number of studies have examined such interactions in older adults. Some studies have found that high levels of PA could ameliorate the negative effects of sedentary behaviour (SB) on obesity (Asp et al., 2017; Chastin et al., 2012). Conversely, other studies found clear associations of SB with overweight and obesity markers as body fat mass, irrespective of PA levels (Gianoudis et al., 2015). Therefore, understanding impact and interactions of movement behaviours on adiposity and obesity in populations living in diverse socioeconomic settings will have important implications to determine the focus of future behavioural interventions.

Existing evidence supports obesity burden rise in older adults due to the increase in disabilities (Peeters & Backholer, 2012), such as sarcopenia and osteoporosis, with an unfavourable impact on functionality and mobility. Physical functioning (including mobility, balance, and fitness) is a major determinant of older adults' independence and quality of life (Trombetti et al, 2016). The most recent WHO recommendations on PA and SB, highlighted the existence of high-certainty evidence demonstrating an inverse dose-response relationship between volume of aerobic PA and risk of physical functional limitations in older adults (Bull et al., 2020). Indeed, previous studies reported a positive association of PA on physical function, with lower prevalence of chronic diseases and reduced mortality risk (Stenholm et al., 2016). The beneficial effect of objectively-measures PA and physical function is well-established in HICs, such as the United States and Australia (Riebe et al, 2005; Yorston et al., 2012), however the association might vary according to different socioeconomic settings. Additionally, there is limited evidence on the combined effect of 24-h movement behaviours as sleep, SB, and different intensities of PA on adiposity and physical functioning indicators in older adults. To date, only one study included functional outcomes (grip strength positively associated with LPA) acknowledging the compositional nature of movement behaviours in older adults (65-79 years) (McGregor et al., 2018) and no previous studies considered an older adult population from LMICs.

Accordingly, this chapter aims to investigate the associations between objectively measured 24-h movement behaviours, adiposity, and physical functioning outcomes (BMI, waist circumference, fat mass, blood pressure, dynamic balance, lower body strength, and aerobic endurance), in representative samples of older adults from Scottish and South African communities. Based on previous literature, it is hypothesised that differences in socioeconomic setting, health status, and obesity prevalence will lead to different associations between movement 24-h behaviours and health outcomes in high and low-income countries. Specifically, it is predicted that older adults engaging in greater MVPA relative to the other behaviours will display better values of adiposity and functional outcomes.

5.2. Methods

Please refer to Chapter 3 and 4 for methods related to participants, anthropometry, body composition, and accelerometry data management.

5.2.1 Waist circumference measurement

Waist circumference (WC) at the level of the umbilicus (cm) was measured using a metal anthropometric tape (Scotland: Seca 201, Birmingham, UK; South Africa: CESCORF, Brazil) on naked skin and noted to the nearest 0.1 cm (World Health Organisation, 2011). Waist circumference values were used to classify older adults with abdominal obesity as: WC >94 cm for men and WC >80 cm for women (World Health Organisation, 2011).

5.2.2 Blood Pressure measurement

Blood pressure was measured three times at 1-min intervals using an appropriately sized cuff and an automated blood pressure monitor (Omron 711, Omron Healthcare, Hamburg, Germany), after body composition assessment to allow participants to rest in a seated position for 30 minutes. The mean of the three measurements is presented. Older adults were classified as having hypertension if systolic blood pressure ≥140 mmHg and diastolic blood pressure ≥90 mmHg (Seedat & Rayner, 2014; Giles et al., 2009).

5.2.3 Chair stand test

Chair stand test (30-second sit to stand) was included to assess lower limb strength. Number of full stands (starting from a sitting position) completed in 30 second with arms folded across the chest were counted for a total of 3 efforts, allowing 3 minutes of rest between each repetition. A chair appropriate for participant's height was chosen. The maximum score achieved across attempts was used as outcome (Jones et al., 1999).

5.2.4 Six-minute walking test

Aerobic endurance was measured with the 6-minute walking test. It was performed once, and the number of meters covered by walking over 6 minutes were measured. The researcher used a stopwatch and walked behind the participant during the test to mark and monitor the distance covered. Participants walked in a 20 x 5 m rectangle (Duncan et al., 2017).

5.2.5 Timed Up and Go test

The recommended test for agility and dynamic balance was performed by using the timed up and go test (TUG) which measures the number of seconds it takes to get up from a seated position, walk 3 meters at a fast speed and return to the starting position. The fastest time of 3 efforts with 1-minute rest in between was used in the analysis (Podsiadlo & Richardson, 1991).

5.2.6 Statistical analysis

Analysis was conducted using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA) and compositional analysis were conducted using the open-source software Physical Activity CoDa Regression Model (PACRM) and CoDaPack software version 2.03.01. Traditional descriptive statistics for adiposity and functional tests were stratified according to Scottish and South African groups. The normality of the data was analyzed by the Kolmogorov–Smirnov test combined with Q-Q plots. Descriptive statistics for continuous variables were expressed as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Categorical variables were expressed as frequency and percentage. Regression assumptions were checked, and in all models non-normally distributed dependent variables were transformed with the most appropriate transformation. To investigate the associations between proportions of time spent in the 24-h movement behaviours, adiposity, and physical functional outcomes, compositional linear regression models were then computed separately for both cohorts. For each cohort, four compositional linear regression models were performed for each variable (BMI, waist circumference, fat mass, systolic and diastolic blood pressure) and physical functioning outcomes (TUG, 6-minute walk test, chair stand test) as response, via isometric log-ratio (ilr) transformation of the time-use composition (explanatory variables) along with covariates. First, the composition of time spent in sleep, SB, LPA and MVPA was considered. A set of three ilr-coordinates was obtained via sequential binary partition. Model p-values and R^2 coefficients were calculated from unadjusted linear regression models to assess the presence of a statistically significant relationship between time use composition and adiposity, blood pressure, and physical functioning components. The first coefficient (γ) and the corresponding p-value for each of the four linear regressions were used to determine if the time spent in a specific behaviour relative to the others was significantly associated with the health outcomes. We further visualised relative differences between the subgroups (low and high WC, BMI groups, and blood pressure categories) with the use of a compositional mean barplot. Outcomes from CoDa analysis should not be interpreted in isolation due to their nature (ratios between behaviours), regression coefficients should be considered relative to the remaining behaviours. To assess the relationship between sleep quality derived from the overall score of the PSQI with adiposity and physical functioning outcomes, we performed linear regression models. Covariates were selected a priori, and all models were adjusted for age, sex, education, smoking status, total physical activity during the week. Statistical significance was set at $p < 0.05$.

5.3. Results

5.3.1 Descriptive statistics

Group differences for adiposity, blood pressure, and physical functioning measures are presented in **Table 19**. South African older adults had a greater prevalence of obesity, higher waist circumference, and higher fat mass compared to the Scottish counterpart. However, when WC was classified in high (WC>102 cm for men and WC>88 cm for women) and low to assess central adiposity, no significant differences across cohorts were found. Scottish older adults displayed higher values of systolic and diastolic blood pressure compared to South African individuals. A higher proportion of Scottish older adults were classified as having hypertension (46%) compared to the South African counterpart (36%), however no significant differences were found for number of people with hypertension. No significant differences were found aerobic endurance (6-minute walking test) across the two cohorts. Conversely, Scottish older adults displayed better lower strength (chair stand test) compared to South African participants. Additionally, Scottish individuals had better values for agility and dynamic balance and timed up and go (TUG) compared to South African older adults.

Table 19. Adiposity, blood pressure, and physical functioning measures for Scottish and South African cohorts

Variables	**Scottish cohort (n=150)**	**South African cohort (n=138)**
Adiposity and blood pressure measures		
BMI-derived obesity (n, %)	**22 (14.6)**	**84 (60.9)****
WC (cm)	**85.5 (79-102)**	**97.2 (87.5-106)****
High WC, yes (n, %)	87 (58)	93 (67)
Fat mass (kg)	**25.4 ±8.9**	**34.8 ±14.1****
Fat mass (%)	**37.5 (31.6-41.3)**	**47.2 (40.7-51.8)****
Systolic blood pressure (mmHg)	**137.2 (126.3-149.2)**	**131.3 (118.9-149.5)***
Diastolic blood pressure (mmHg)	**81.4 (72.9-86.4)**	**71.7 (64.5-79.5)****
Hypertension, yes (n, %)	69 (46.0)	49 (35.5)
Physical functioning measures		
Chair stand test (n)	**18.0 (15.0-21.0)**	**10.0 (10.0-13.0)****
6-minute walking test (m)	466 (417.1-534.4)	470 (410.1-522.5)
TUG test (sec)	**4.4 (4.0-4.9)**	**6.6 (5.9-7.4)****

*All normally distributed and skewed data are reported as mean ± SD and Median (IQR – 25-75th percentile), respectively. Abbreviations: BMI, Body Mass Index. WC, waist circumference. TUG, timed up and go. P values represent a significant difference between groups. Parametric and non-parametric (Mann-Whitney U) independent t-tests were conducted on normally distributed and skewed data, respectively. Chi-square was used to determine differences in frequency of each variable between Scottish and South African cohorts. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

5.3.2 Composition of the day by groups for Scottish older adults

Relative distribution of 24-h movement behaviours for each subgroup is presented as geometric mean bar plot with the log-ratio between the group compositional mean and the overall compositional mean after centering the data. Positive and negative values show that the group geometric mean is larger and smaller, respectively, than the entire population. **Figure 19** represents time-use compositions for Scottish older adults stratified according to high and low WC. In the Scottish high WC group, MVPA is reduced by 5% relatively to the overall mean composition (**Figure 19**), while it is reduced by 35% in the obese category (**Figure 20**). Scottish older adults with hypertension presented MVPA reduced by 23% relatively to the whole sample (**Figure 21**).

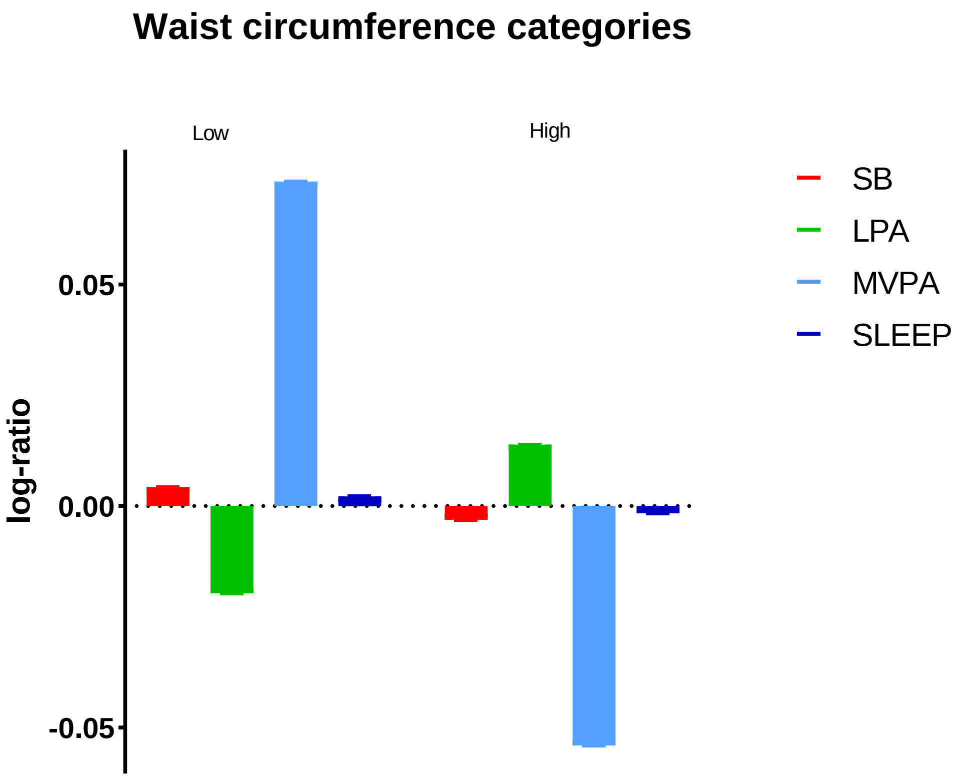


Figure 19. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by group of waist circumference for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

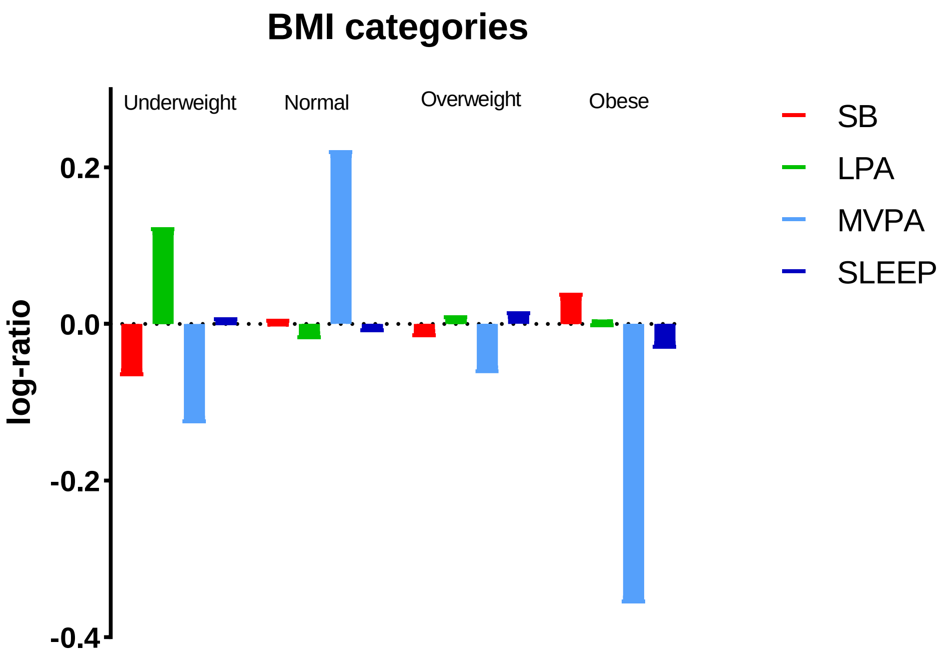


Figure 20. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by BMI group for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

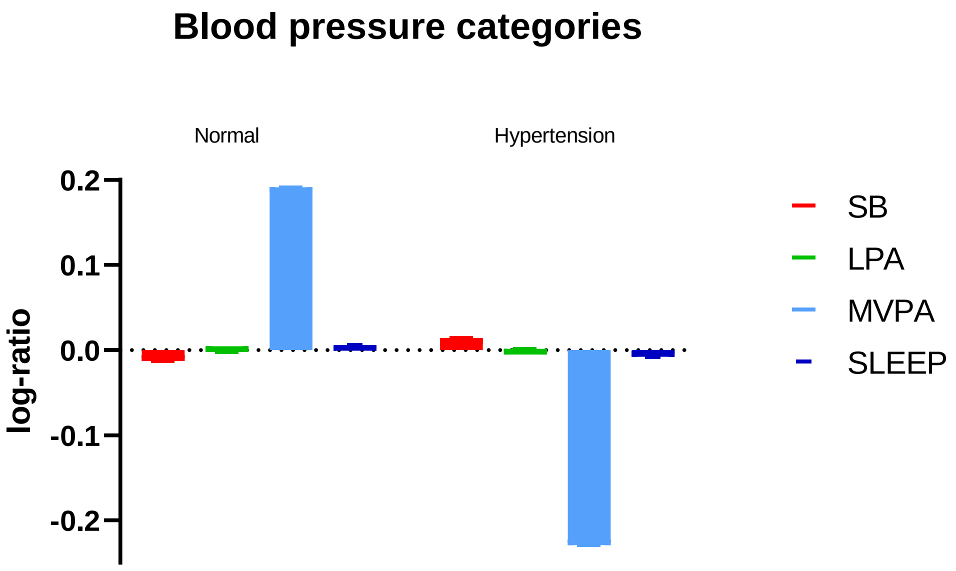


Figure 21. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by blood pressure group for Scottish older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

5.3.3 Composition of the day by groups for South African older adults

Figure 22 represents time-use compositions for South African older adults stratified according to high and low WC. In the high WC group, MVPA is reduced by 10% relatively to the overall mean composition (**Figure 22**), while it is reduced by 20% in the overweight category (**Figure 23**). Participants classified as underweight displayed the lowest MVPA value relative to the mean of the overall sample. South African older adults without hypertension had a greater volume of MVPA (increased by 10%) relatively to the whole sample (**Figure 24**).

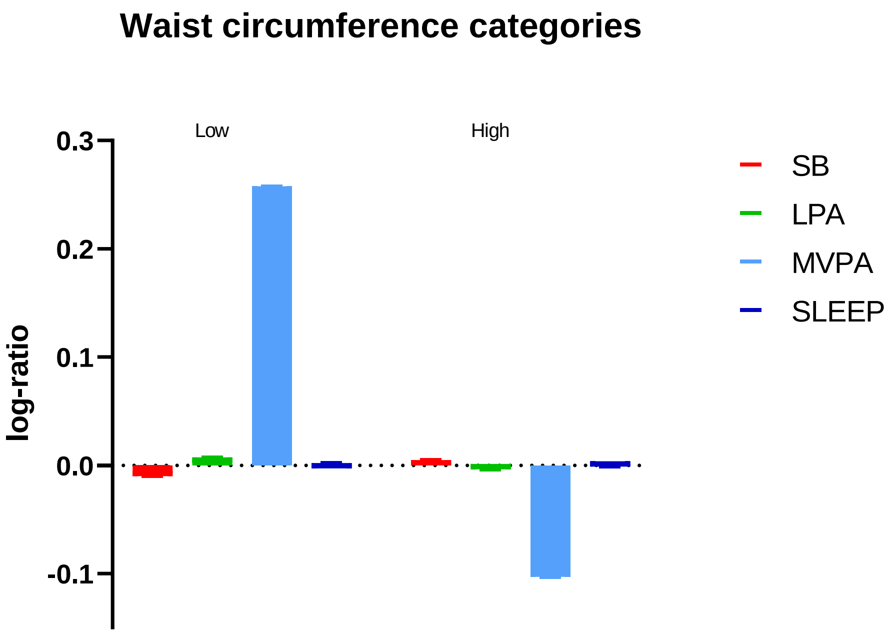


Figure 22. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by group of waist circumference for South African older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

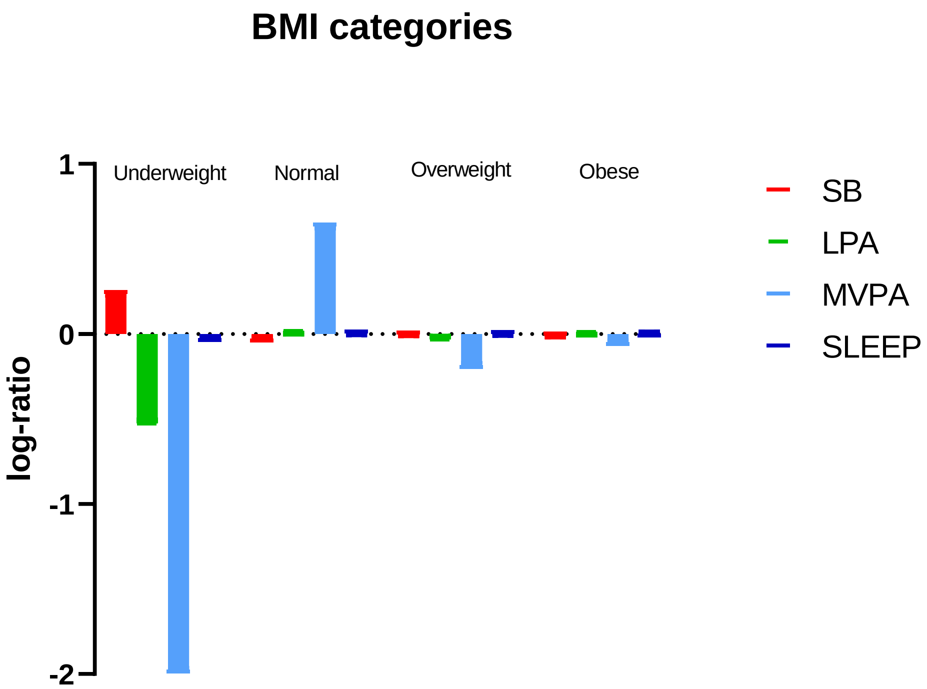


Figure 23. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by BMI group for South African older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

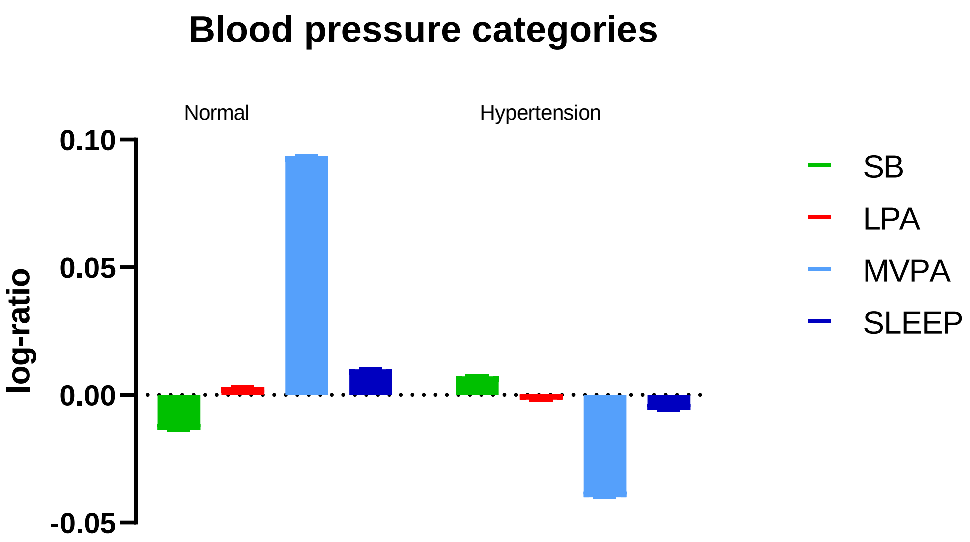


Figure 24. Compositional analysis of the relative importance of the group mean time spent in SB, LPA, MVPA, and sleep with respect to the overall mean time composition by blood pressure group for South African older adults. Each bar represents the ratio on a logarithmic scale of a movement behaviour between the geometric mean of the group and that of entire sample. Positive and negative values show that the group geometric mean is larger or smaller than the whole sample.

5.3.4 Relationship between 24-h time use composition, adiposity, blood pressure, and physical functioning outcomes in Scottish and South African older adults

Compositional linear regression models in relation to adiposity markers and blood pressure measure are shown in **Table 20** and **Table 21** for Scottish and South African older adults, respectively. In the South African cohort, more time spent in SB relative to the other behaviours was consistently associated with higher adiposity measures. Specifically, longer relative time spent in SB was associated with higher values of BMI, WC, and fat mass (kg) in South African older adults. Additionally, WC was negatively associated with nocturnal sleep and positively associated with MVPA in the South African sample. In both cohorts, the overall 24-hour time use composition accounted for a similar proportion of the variance for fat mass. However, in the Scottish sample, MVPA appeared to consistently drive the association between movement behaviours and adiposity determinants. The overall 24-h time use compositions were significantly associated with adiposity outcomes, with a variance explained ranging from ±6% to ±13%. No significant associations were found between 24-h movement behaviours and blood pressure measures in both cohorts. However, an association between overall 24-hour composition and systolic blood pressure was only reported in the Scottish sample and accounted for ± 6% of the variance. Significant associations between 24-h movement behaviours and physical functioning outcomes were found in South African older adults, with a variance explained ranging from ±16% for lower body strength to ±31% for aerobic endurance. Specifically, relative time spent in MVPA was associated with better scores for functional tests. SB was negatively associated with the chair stand and 6-minute walking tests. Nocturnal sleep duration was also positively associated with lower body strength from the chair stand test in South African older adults. Conversely, no significant associations were found between 24-h movement behaviours and physical functioning outcomes in the Scottish cohort.

Table 20. Compositional linear regression for the associations between movement behaviours, adiposity, blood pressure, and physical functioning outcomes in the Scottish cohort					
	γ sleep	γ SB	γ LPA	γ MVPA	Model R^2
Scottish cohort					
BMI (kg/m^2)	-0.09	0.94	0.85	**-1.70****	**0.07***
WC (cm)	-2.79	9.26	-2.83	**-3.64****	**0.06***
Fat mass (kg)	2.07	0.23	1.26	**-3.56****	**0.06***
Fat mass (%)	3.48	0.96	-1.37	**-3.08****	**0.13****
Systolic blood pressure (mmHg)	-5.68	3.81	5.33	-3.46	**0.06***
Diastolic blood pressure (mmHg)	4.57	-4.70	-0.41	0.54	0.01
TUG test (sec)	-0.40	0.28	0.13	-0.01	0.02
6-minute walking test (m)	35.29	**-62.43***	31.87	4.73	0.02
Chair stand test (n)	2.54	**-4.23***	1.46	0.21	0.02

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Model p-value and R^2 are based on the unadjusted model. Regression coefficients and corresponding p-values were adjusted for age, sex, education, and smoking status. Blood pressure and physical functioning variables were further adjusted for Body Mass Index (BMI). Abbreviations: BMI: Body Mass Index. WC, waist circumference. TUG, timed up and go.Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

Table 21. Compositional linear regression for the associations between movement behaviours, adiposity, blood pressure, and physical functioning outcomes in the South African cohort					
	γ sleep	γ SB	γ LPA	γ MVPA	Model R^2
South African cohort					
BMI (kg/m^2)	-5.68	**7.42***	-2.01	0.27	0.07
WC (cm)	**-17.43***	**18.59****	-3.81	**2.66***	0.03
Fat mass (kg)	-8.38	**12.64***	-4.70	0.43	0.05
Fat mass (%)	-0.48	4.29	-3.57	-0.25	**0.13****
Systolic blood pressure (mmHg)	18.30	-7.72	-11.09	0.51	0.01
Diastolic blood pressure (mmHg)	0.63	4.32	-5.04	0.09	0.03
TUG test (sec)	0.31	0.75	-0.53	**-0.53****	**0.29****
6-minute walking test (m)	15.14	**-71.67***	38.38	**18.15***	**0.31****
Chair stand test (n)	**3.06**	**-2.90***	-0.95	**0.73****	**0.16****

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Model p-value and R^2 are based on the unadjusted model. Regression coefficients and corresponding p-values were adjusted for age, sex, education, smoking status, diabetes and human immunodeficiency virus (HIV) prevalence. Blood pressure and physical functioning variables were further adjusted for Body Mass Index (BMI). Abbreviations: BMI: Body Mass Index. WC, waist circumference. TUG, timed up and go. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

5.3.5 Sensitivity analysis

In the compositional regression models for the South African sample, we adjusted for the two main diseases that were different in the cohorts (HIV and diabetes). Results of the sensitivity analysis on the subsample of South African participants (excluding diabetes and diabetes + HIV) are presented in **Table 22**. Statistical significance from these models follows the similar pattern as the models presented in **Table 22**. However, some results are attenuated possibly by the restricted sample size. Specifically, SB does not appear to influence physical functional outcomes in the South African cohort when individual with diabetes and HIV are removed.

Table 22. Subsample analysis for compositional linear regression for the associations between movement behaviours and musculoskeletal outcomes

Variables	**γ sleep**	**γ SB**	**γ LPA**	**γ MVPA**	**Model R^2**
South African cohort (no diabetes, n=107)					
BMI (kg/m^2)	-3.99	**7.85***	-4.23	0.38	**0.35**
WC (cm)	**-16.11***	**18.83****	-5.40	**2.68***	**0.20**
Fat mass (kg)	-8.64	**15.07***	-7.31	0.88	**0.39**
Fat mass (%)	-0.67	6.11	-5.25	-0.20	**0.64**
Systolic blood pressure (mmHg)	6.15	-2.36	-6.50	2.67	0.04
Diastolic blood pressure (mmHg)	-4.06	6.84	-3.88	1.09	0.11
TUG test (sec)	0.70	0.04	-0.24	**-0.50****	**0.32**
6-minute walking test (m)	-11.89	-34.85	28.87	**18.19****	**0.46**
Chair stand test (n)	2.88	**-1.99***	-1.79	**0.90****	**0.21**
South African cohort (no diabetes and no HIV, n=98)					
BMI (kg/m^2)	-3.89	**7.46***	-3.88	0.32	0.05
WC (cm)	**-16.83***	**16.67***	-2.09	2.25	0.05
Fat mass (kg)	-8.33	**13.46***	-5.84	0.71	0.06
Fat mass (%)	-1.27	5.36	-3.71	-0.39	**0.18**
Systolic blood pressure (mmHg)	2.76	-2.81	-1.65	1.70	0.01
Diastolic blood pressure (mmHg)	-6.29	7.84	-2.11	0.56	0.05
TUG test (sec)	0.95	-0.21	-0.29	**-0.45****	**0.21**
6-minute walking test (m)	-28.56	-23.35	37.26	**14.66***	**0.25**
Chair stand test (n)	2.16	-1.44	-1.48	**0.76****	**0.11**

*Compositional regression coefficients (γ) for each movement behaviour represent the association for time spent in each behaviour relative to all other behaviours. Model p-value and R^2 are based on the unadjusted model. Regression coefficients and corresponding p-values were adjusted for age, sex, education, and smoking status. Gait speed and bone mineral density (BMD) variables were further adjusted for Body Mass Index (BMI). The first model was additionally adjusted for HIV prevalence. Statistically significant results are highlighted in bold: *p<0.05 .**p<0.01.*

5.3.6 Association between sleep quality, adiposity, and functional outcomes in Scottish and South African samples

No significant associations were found in linear regression models between sleep quality (PSQI overall score) and BMI (P=0.98), WC (P=0.91), fat mass (P=0.63), systolic (P=0.96) and diastolic (P=0.60) blood pressure, agility (P=0.90), aerobic endurance (P=0.86), and lower body strength (P=0.14) in Scottish older adults. Additionally, no significant associations were found between sleep quality (PSQI overall score) and BMI (P=0.79), WC (P=0.63), fat mass (P=0.79), systolic (P=0.29) and diastolic (P=0.09) blood pressure, agility (P=0.83), aerobic endurance (P=0.39), and lower body strength (P=0.21) in the South African sample.

5.4. Discussion

5.4.1 Scottish sample

In the Scottish sample, lower values of BMI, central adiposity (waist circumference), and fat mass were associated with higher time spent in MVPA relative to the other behaviours, highlighting MVPA as main activity type driving the association between daily movement behaviours and obesity markers. Our finding is in agreement with previous compositional and conventional evidence (Dumuid et al., 2018; Zhu et al., 2020) attributing beneficial associations to MVPA with adiposity and body composition outcomes. Additionally, current evidence is strongest for time reallocation to MVPA, when 15 minutes of SB are replaced to MVPA a decrease of 0.7 BMI points was found in older adults (Dumuid et al., 2018). Another longitudinal study in European older women found that the greatest change to a lower BMI was driven by replacement from SB to MVPA (Pelclova et al., 2018). Therefore, our results confirmed the beneficial effect of MVPA, at the expense of other movement behaviours, on adiposity outcomes in a Scottish cohort of older adults.

No associations between a specific movement behaviours and blood pressure were found. Contrasting findings are present with previous conventional analytical approaches generally supporting the presence of such association (Brook et al., 2013; Pescatello et al., 2004). Conversely, most compositional studies in older adults do not support the existence of a relationship between 24-h movement behaviours and blood pressure in older adults (McGregor et al., 2018; Dumuid et al., 2018; Gupta et al., 2018). Indeed, our findings support previous evidence suggesting that associations between 24-h movement behaviours and cardiometabolic outcomes are stronger for obesity outcomes (BMI, WC, and fat mass) than for blood pressure outcomes (McGregor et al., 2018). However, the movement behaviour driving the difference between Scottish older adults with and without hypertension appears to be the relative time in MVPA. This suggests a potential protective role of MVPA on blood pressure. Therefore, given the mixed evidence, future research on movement behaviours should further explore systolic and diastolic blood pressure as health outcomes in older adults.

In Scottish older adults, time spent in SB relative to the other behaviours was negatively associated with aerobic endurance (6-minute walking test) and lower body strength (chair-stand test). Specifically, participants spending longer time in sedentary activities displayed worse functional scores compared to older adults with less time in SB. These results are in line with evidence from European older adults showing that total SB volume had a negative association on physical function, with low distances achieved and long chair stand times in participant with high sedentary time (Wilson et al., 2021). SB and physical function are likely to be linked in a negative feedback loop, with poor function leading to longer SB, further promoting reductions in function and detrimental health outcomes (Reid et al., 2018). Additionally, decline in physical function can lead to lower independence and increased risk of disability in older adults (Colon-Emeric et al., 2013). Thus, it is important to identify strategies to support the prevention of physical function loss and our findings support the role of SB as a modifiable risk factor to target in Scottish older adults.

5.4.2 South African sample

Body composition and adiposity outcomes (BMI, WC, and fat mass) were mainly associated with the time spent in SB relative to the other behaviours in South African older adults. No beneficial associations between relative time in MVPA and obesity markers were found, which could be partly explained by the low engagement in MVPA in the included sample. This finding in South African older adults agrees with previous evidence from a Spanish older adult population (Gomez-Cabello et al., 2012) and a sample of European older women (Gaba et al., 2021), highlighting an association between increases in sedentary time with increased BMI and body fat. A previous study including older adults from six LMICs found that, independent of PA, longer self-reported daily sitting time was significantly associated with obesity (Gaskin & Orellana, 2018). However, no previous studies considered the co-dependence of movement behaviours in low-income settings. Additionally, in this study, obesity prevalence achieved 61%, this high rate could be explained by the high prevalence of women included in the experiment (80%). Indeed, previous data shown that South African women have the highest prevalence of overweight and obesity in sub-Saharan Africa (68%). Low-income settings are often characterised by higher prevalence of obesity and the link between obesity and negative health consequences is well established. For example, obesity has been linked with reduced quality of life and functional capacity in older age (Houston et al., 2009), changes in skeletal muscle and cardiometabolic health (Straight et al., 2021; Sinclair & Abdelhafiz, 2020), which can lead to health complications (such as metabolic syndrome and diabetes). Our results further reinforce the idea of the deleterious effects of the relative time spent in SB on obesity markers in older adults in a low-income setting. These findings support the need for integration of 24-h movement behaviours in guidelines targeting the volume of SB. However, 24-hour movement guidelines are currently present only for a high-income country (Canada) (Ross et al., 2020) and WHO PA and SB guidelines omit sleep guidance. Therefore, future research should consider expanding the evidence base to inform the development of contextually relevant 24-h movement guidelines to older adults in LMICs as a means to promote healthy ageing that encompasses all movement behaviours.

The present Chapter shows a significant negative association between nocturnal sleep duration and central adiposity in South African older adults. Specifically, older adults accumulating shorter sleeping durations displayed greater values of WC, compared to older adults sleeping longer. Our results agree with previous evidence (Peltzer & Pengpid, 2017) and a meta-analysis highlighting a significant association between insufficient sleep and waist circumference (Sperry et al., 2015). A possible mechanism for the short sleep duration and obesity association is that chronic sleep restriction influences cardiovascular and metabolic health (Mullington et al., 2009), with physiological consequences including impaired glucose regulation and insulin sensitivity (Spiegel et al., 2009). Despite the existing evidence for the negative effects of decreased sleep quality and duration, research is limited, particularly in low-income settings, on sleep interventions as a behavioural approach to improve body composition in individuals who have or are at risk for developing obesity. Future longitudinal and intervention studies are required to address this research gap.

In the South African sample, higher time spent in MVPA relative to the other behaviours was associated with better physical functioning outcomes (agility and dynamic balance, lower body strength, and aerobic endurance). Conversely, the relative time spent in SB was negatively associated with aerobic endurance and lower body strength (not with TUG scores). Previous studies, considering MVPA in isolation, have consistently reported favorable effects of high PA intensities on physical function in older adults (Yorston et al., 2012). A recent study, relying on isotemporal substitution analysis, found the replacement of time in SB or LPA with MVPA has beneficial effects on agility and dynamic balance with improvements in TUG scores in a sample of Japanese older adults (Yasunaga et al., 2017). Physical functioning is an important domain of successful ageing definition (Bowling & Dieppe, 2005) and it is associated with disability and mortality in older adults (Fielding et al., 2017). While the beneficial effect of MVPA in isolation on physical functioning is already well-established, recent evidence argued whether this positive impact remained when the whole day is considered. Our findings confirm the protective role of MVPA on agility and dynamic balance, lower body strength, and aerobic endurance in a South African setting.

5.4.3 Comparison of Scottish and South African samples

In the South African cohort a higher prevalence of obesity was found compared to the Scottish counterpart. This finding agrees with previous evidence highlighting that LMICs are often characterized by a higher prevalence of obesity compared to HICs. Obesity has negative consequences on physical and mental health in older adult, including increased prevalence of chronic diseases, decreased quality of life, and increased health care costs (Decaria et al., 2012; Malenfant & Batsis, 2019). Scottish older adults displayed significantly higher values of blood pressure and a greater number of participants were classified as having hypertension. However, recent evidence suggested that prevalence and absolute burden of hypertension is rising globally, especially in LMICs (Schutte et al., 2021).

In both cohorts, physical function (aerobic endurance and lower body strength) was negatively associated with longer time spent in SB relative to the other behaviours. Our finding is in agreement with previous evidence from Portuguese and Australian older adults with accelerometer-derived SB (Santos et al., 2012). However, compared to previous studies (Hrubeniuk et al., 2020), we assessed physical functioning capacity with objective measurements of physical performance in older adults, avoiding cognitive and emotional influences on self-reported outcomes (Knauper et al., 2016). Our results suggest that interventions targeted at older adults should consider the importance of avoiding prolonged time spent in SB, irrespective of the sociodemographic profile. Additionally, greater engagement in MVPA relative to the other behaviours in South African older adults promoted better dynamic balance and agility, aerobic endurance, and lower body strength.

Thus, the importance of meeting PA recommendations should be reinforced in older adults from LMICs in order to sustain beneficial effects that PA has on physical function.

Context-specific associations of 24-h movement behaviours on adiposity and physical function were found. Relative time in MVPA was driving the associations with BMI, waist circumference, and fat mass in Scottish older adults. Conversely, time spent in SB relative to the other behaviours was the main determinant in the associations with adiposity markers for the South African sample. Differences in associations between health outcomes and 24-h movement behaviours could be explained by differences in time use compositions (presented in Chapter 3) and in health status. Specifically, low engagement and restricted variance in MVPA in the South African sample could explain the lack of relationship. The greatest contributor to PA in South African older adults was light PA (LPA). Previous studies highlighted beneficial effects of LPA on physical health, wellbeing, and prevention of cognitive deterioration in later life (Buman et al., 2010; Pau et al., 2014). Therefore, despite the lack of associations between PA variables and adiposity outcomes in the South African cohort, LPA is valuable and should not be discounted. Overall, these context-specific effects support the complexity of the examined associations. In agreement with previous studies (Van Dyck et al., 2020), it can be suggested that strategies to prevent obesity and physical functioning decline in older adults through a focus on 24-h movement behaviours might not be equally effective and should be adapted to different socioeconomic settings. Therefore, findings identified in this Chapter may have important implications in the context of addressing movement behaviours guidelines to help prevent obesity in older adults living in diverse settings.

There are factors to account for when considering the results from this Chapter. First, previous evidence suggests that unassessed context-specific variables (e.g. dietary patterns and perceptions of the built environment) may play a confounding role on 24-h movement behaviours. Specifically, energy intake assessment and the consideration of environmental aspects associated with food intake (for example, low-income settings are associated with lower access to healthy food options (Gundersen & Ziliak, 2015; Pirkle et al., 2020)) could attenuate or reinforce the association between movement behaviours and adiposity outcomes. Therefore, future international studies combining data of diverse socioeconomic settings should be encouraged to further investigate these complex associations. Second, different instruments were used for multiple measures (body composition and anthropometry), which meant that a direct comparison between the

Scottish and South African participants for multiple measures was not feasible. Regardless, this does not preclude the comparison of associations between 24-h movement behaviours and adiposity outcomes. Third, as this is a cross sectional study, it is not possible to infer a cause-and-effect relationship between movement behaviours, adiposity, and physical function. This is an important issue because behaviours pattern may reflect obesity and/or functional status. Thus, future longitudinal studies are needed to address this limitation.

5.5. Conclusion

In this Chapter, we highlighted the presence of context-specific associations between 24-h movement behaviours and health outcomes in older adults living in diverse socioeconomic settings. Specifically, in the Scottish cohort, longer time engaging in MVPA relative to the other behaviours was consistently associated with lower adiposity values for BMI, waist circumference, and fat mass. Conversely, SB was the main activity determining associations between movement behaviours and adiposity outcomes in the South African sample, with longer time spent in SB associated with worse BMI, waist circumference, and fat mass. Therefore, an appropriate behavioural approach for obesity management could be to facilitate balanced distribution of time spent in movement behaviours across domains throughout the day considering differences in sociodemographic profile. Several recent public health recommendations advocate reducing SB and increasing PA engagement for maintaining better adiposity and physical functioning outcomes (Bull et al., 2020; Fuzeki & Banzer, 2018). Our findings provide empirical evidence supporting these recommendations. However, given the degree of PA inequality in LMICs (Chastin et al., 2020; Althoff et al., 2017), movement behaviours guidelines should be accompanied by national plans and policies to ensure equitable access to PA engagement. Consequently, future interventions need to be tailored to the socioeconomic factors and realities of public spaces and infrastructures in LMICs.

Chapter 6: General discussion and conclusions

6.1 Overview

The main aim of this PhD thesis was to investigate changes in walking behaviour with ageing in a sample of Scottish adults and the associations of 24-h movement behaviours with health outcomes affecting mobility in older adults living in diverse socioeconomic settings. Specifically, the aims of this thesis were:

1) to determine differences in usual and physically-challenging walking conditions (gait phases and muscle activity) during ageing in adults and older adults living in Scotland
2) to examine the associations of objectively measured 24-h movement behaviours with musculoskeletal, body composition, and physical functioning outcomes in Scottish and South African communities of older adults.

With populations ageing worldwide, there is an increasing need for evidence-based research and interventions to promote independence in older people to ensure good quality of life with advancing age. Mobility, defined as the ability to move efficiently within the environment (Webber et al., 2010), is a fundamental component in completing basic activities of daily living in older adults and is the integrated results of the functioning of different systems (musculoskeletal, sensory, and cognitive) (Rantanen, 2013). Previous evidence highlighted the importance of mobility performance for prognostic disability with advancing age (also in high-functioning older adults) (Wennie Huang et al., 2010; Guralnik et al., 1994). Indeed, older adults with reduced functional mobility tend to lose independency and are less likely to remain in the community, with experience of poor quality of life and high likelihood of depression and social isolation (Iezzoni et al., 2003; Shankar et al., 2017). The prevalence of self-reported mobility issues in older adults is large, ranging from 42% to 76% of people aged 65+ reporting difficulties in walking or climbing stairs in low-middle income countries (LMICs) (Capistrant et al., 2014) and around 60% of older adults aged 60+ in the UK (Gale et al., 2014). It is, therefore, important to explore different factors affecting movement in adults and older adults to identify suitable approaches and prevent development of future disabilities.

Results from Chapter 2 showed that, in laboratory-based conditions, high-functioning older adults (60+) presented age-related changes in walking behaviour, with a more cautious gait and greater walking effort (defined as higher muscle activation) compared to both young (18-40) and middle-aged adults (40-60). To date, few studies have included a middle-aged adult group for the purpose of comparison (Herssens et al., 2018). In previous studies, different age groups showed similar gait performance or moderate age effect in lower limb motion during usual walking (Chung & Wang, 2010; Jin & Hahn, 2019). Additionally, in a recent study, middle-aged adult's walking performance was not different from young adults when crossing low obstacles. However, as obstacle height increased, age-related changes were present, with middle-aged adults displaying a more similar walking behaviour of the older adults (Muir et al., 2019). The findings presented in this thesis support previous mentioned evidence highlighting age-related changes in walking behaviour both on flat and uneven surfaces. Walking is an integral component of mobility and one of the most reported type of physical activity (PA) in older adults (Valenti et al., 2016). Results from Chapter 2, demonstrated an increase in walking effort with ageing, highlighting that older adults require greater percentages of their neuromuscular capacity during walking than young and middle-aged adults. Additionally, a possible explanation for the cautious walking approach in older adults could be the need to compensate for a reduction in muscle strength. Participants taking part in the experiment described in Chapter 2 were healthy adults and older adults, nevertheless differences in muscle activation dynamics and temporal gait parameters were found. Consequently, the observed age-related changes could potentially be more pronounced in older adults who are less active or inactive. Previous evidence highlighted the association of increased walking effort in older adults with reduced stepping time (LaRoche et al., 2018). Indeed, walking effort influences daily activities and movement behaviours with a tendency to avoid effortful activities (Crombie et al. 2004). Additionally, a greater effort contributes to an increase in the perceived fatigability resulting in early termination of an activity (Egerton et al. 2015). Therefore, exercise interventions targeting neuromuscular capacity and muscle strength in older adults might positively impact upon 24-h movement behaviours.

Results in Chapter 2 are limited by the artificiality of the laboratory setting and the reduced time frame considered, leading to uncertainty when generalising findings to real-life settings. Additionally, individual capacity is only one of the components of functional mobility in older people. Socioeconomic status, neighbourhood physical and social environments are major predictors of older adult movement behaviours and health status (Chaudhury et al., 2016; Browning & Cagney, 2003). Accordingly, we aimed to expand laboratory-based measurements of mobility into the real world by considering movement within the whole 24-h period and including groups of older adults living in diverse socioeconomic settings. Low-income settings are often characterized by both a high prevalence of obesity (Ford et al., 2017) and communicable and non-communicable diseases (Kampfen et al., 2018; Kankeu et al., 2013). Evidence suggests that differences in living conditions and sociodemographic factors contribute to greater exposure and vulnerability to unhealthy behaviours (Pampel et al., 2010), leading to differences in general health status across socioeconomic settings. This is particularly evident in South Africa. Importantly, older adults living in South African townships have been shown to have poorer health outcomes, limited access to health care resources, and lower life expectancy compared to high-income settings (Abegunde et al., 2007). Consequently, older adults in LMICs are likely to experience more serious impacts on their wellbeing than tends to be experienced in high-income countries (HICs). However, little is known on how differences in health status and 24-h movement behaviours in LMICs and HICs can affect mobility via musculoskeletal health and body composition of older men and women living in these settings. Interestingly, previous authors argued that the field of movement behaviours and health was biased by the fact that most research took place in HICs (Palma & Assis, 2011), leading to an underrepresentation of LMICs with the possibility that previous findings are less applicable for low-income settings. Researchers were all from developed countries and studied variables that were relevant for populations in their own countries. Therefore, it is important to include comparison of sociodemographic profiles in movement behaviours to identify consequences on health inequalities across groups.

Results reported in Chapter 3 describe 24-h time use compositions considering movement behaviours in Scottish and South African older adults. The samples had a similar amount of total PA during the week of data collection. Previous evidence reported mixed results on the association between socioeconomic variables and PA outcomes (Gidlow et al., 2006; Beenackers et al., 2012; Stalsberg & Pedersen, 2018). One reason for this, could be the definition of SES variable across studies. From results presented in Chapter 3, differences were present in PA intensities, supporting the idea of differences in time allocation to movement behaviours in diverse socioeconomic settings. Certainly, Scottish older adults displayed higher amount of moderate-to-vigorous PA (MVPA) compared to South African counterparts. This finding agrees with previous evidence highlighting high engagement in leisure MVPA in high-income settings (Stalsberg & Pedersen, 2018). Conversely, we found low time spent in MVPA relative to the other behaviours in the South African sample with a restricted number of older adults meeting PA recommendations for aerobic exercise, which are common issues of LMICs (Strain et al., 2020). These findings support the idea that differences across socioeconomic settings could be restricted to differences in structured leisure MVPA (Stalsberg & Pedersen, 2018), whereas other PA domains such as transport-based and occupational PA had been overlooked. Leisure MVPA is often costly and in low-income settings are characterised by greater degrees of poor and overcrowded environments, lack of safety, and inaccessibility to recreational facilities for organised leisure PA (Lambert et al., 2020). Consequently, interventions targeting organised leisure MVPA might be less effective to ameliorate health and social inequalities. Thus, where possible, the focus of future interventions should be on facilitating access for people who cannot afford it or who perceive access to be a barrier. Future interventions should also be co-designed with participants in order to enhance the efficacy (Bauman et al., 2016).

In Chapter 4 and 5, associations between 24-h movement behaviours and mobility-related health outcomes were investigated and presented. Indeed, common musculoskeletal disorders of old age including osteoporosis and sarcopenia are associated with mobility disability (Guralnik et al., 2001), potentially leading to functional decline and disability. Adequate musculoskeletal health is essential to enable PA, to actively participate in all aspects of life, and to reduce the impact of obesity (Briggs et al., 2016). Globally, disability impact of musculoskeletal conditions is causing 21.3% of the total years lived with disability (YLDs) along with an increasing burden in LMICs (Briggs et al., 2016). Additionally, functional decline and mobility disability due to obesity in ageing have been reported in different populations (Vincent et al., 2010), with several studies reporting increased risk for mobility impairment with higher values of BMI and WC regardless of ethnicity and gender (Vincent et al., 2010). Available evidence indicates that both increased adiposity and reduction in skeletal muscle strength and mass influence development of mobility and functional impairments (Stenholm et al., 2009). High volume of MVPA had a consistent positive effect on muscle strength, muscle mass, and adiposity outcomes (BMI, WC, and fat mass) in the Scottish older adults. No other relevant associations were found with the remaining movement behaviours. In the South African sample, high volume of MVPA was positively associated with better physical functioning outcomes. Additionally, South African older adults spending longer time in sedentary behaviour (SB) displayed significantly worse adiposity outcomes. Therefore, the influence of PA domains among groups of older adults in different socio-economic settings should be considered.

6.2 Limitations

The original thesis plan also involved the recruitment of a subsample of 20 females aged 60-85 years living in Scotland and South Africa, who have previously taken part in the main study presented in Chapter 3, 4 and 5. I aimed to start the lab-based data collection on neuromuscular aspects in March 2020. Specifically, I was going to perform a motor unit assessment through iEMG and sEMG (similarly to the first lab-based study described in Chapter 3) on a thigh muscle (Vastus Lateralis) and shin muscle (Tibialis Anterior) of the same leg and collect self-reported data on PA with the administration of the Global Physical Activity Questionnaire. According to my preliminary data analysis, low muscle mass values were present in the sample populations. However, functional outcome and general muscle strength were well preserved during walking in Scottish older adults (Chapter 1) and from physical functioning tests in both South African and Scottish older adults (Chapter 5), suggesting the presence of an ongoing compensatory process from a neuromuscular perspective. Additionally, previous evidence demonstrated that walking, both as exercise and as a mode of transportation, is the physical activity of choice among ethnically diverse older adults (Belza et al., 2004). Therefore, it is important to investigate the effect of ageing process on the number and size of motor units on lower limb muscles involved in walking and to assess the association of PA, lower limbs neural motor unit functioning, and physical functioning. With this study, I was going to obtain data on mechanisms underlying sarcopenia with possible implications in developing novel interventions to ameliorate age related decline in motor performance, mobility, and physical activity. I was unable to start the subsample data collection as planned due to the COVID-19 pandemic outbreak in March 2020.

The results presented in Chapter 3, 4 and 5 should be considered in relation to the idea that movement behaviours are the products of individual, cultural and community factors and highly influenced by the physical environment and social context (Piggin, 2020). These factors interact across different levels, therefore a more holistic approach to define a given behaviour is needed. Particularly, in LMICs, socioeconomic status and built environment act as barriers to leisure time physical activity (Cleland et al., 2019) and previous evidence supports the idea that movement behaviours are outside of an individual's own volition (Micklesfield et al., 2013). For example, a previous study highlighted poor environmental conditions such as a high crime rate and overcrowding as barriers to engagement in PA (Puoane & Mciza, 2009). Additionally, another study involving South African women reported issues with the acceptability of wearing tight-fitting clothing when participating in sport, as well as the perception that participating in leisure-time PA takes time away from household chores (Micklesfield et al., 2013). However, the role of culture and body image as determinants of movement behaviours are not comprehensively considered in PA research and policy. These factors are fundamental to include in behaviour change interventions to be effective as they can provide culturally adapted frameworks and models to a specific social and physical context to support the desired behaviour change. Therefore, future studies should consider the use of a minimum set of common measures, qualitative approaches, and continuous audit to enhance movement behaviours perspectives in different populations.

Another important factor to consider in relation to the results presented in Chapter 3,4, and 5 is the association between seasonality and movement behaviours. For example, a previous retrospective study involving Scottish older adults and objective measures of daily PA over 1-week period showed that participants enrolled in summer were twice as active as those enrolled in winter (Sumukadas et al., 2009). Specifically, temperature, day length, and duration of sunshine were able to explain 73% of variance in daily activity levels, and these parameters were all independently associated with variation in PA (Sumukadas et al., 2009). A longitudinal study on older adults living in Japan observed seasonal changes in steps per day over a 450-day period (Togo et al., 2005). It is possible that high or low temperatures, rain, and wind might have influences on movement behaviours. However, no previous studies have investigated the association between PA and climatic environment in South Africa. Therefore, the effect of weather on movement behaviours should be taken into account in the interpretation of Chapters results and future studies should investigate the role of climate as barrier for PA as it relates to outdoor recreation or work activities.

Several national and international physical activity guidelines recommend regular muscle-strengthening activities for adults and older adults. For example, according to the most recent WHO guidelines, older adults should engage in muscle strengthening activities at least 2 times per week (World Health Organization, 2020). A limitation of this thesis is that prior strength PA background of the participants has not been assessed. However, previous evidence showed that regular engagement in muscle-strengthening activities increases or preserves skeletal muscle strength and contrast sarcopenia in older adults (Veen et al., 2021). Additionally, it is well-supported the myotrophic role of muscle strengthening activities (Schoenfeld et al., 2016) with beneficial effects on fall risk (Ishigaki et al., 2014) and on activities of daily living (Chou et al., 2012). A recent published systematic review and meta-analysis of cohort studies found that muscle-strengthening activities are inversely associated with the most common non-communicable diseases (cancer, diabetes, cardiovascular diseases) independent of aerobic activities among adults aged 18+ years old (Momma et al., 2022). Given the importance of strength PA, future studies should include specific measure for these kinds of activities as they could have an influence not only on muscular aspects but also on health status.

A recurring theme in feedback received through peer-review, in regards of the experiment outlined in Chapter 3 and Chapter 4 was differences in health status and inclusion criteria (participants with diabetes in Scottish data collection) between the Scottish and South African sample. The aim of the experiments was not to match the 2 samples, rather was to present differences in 24-h movement behaviours and their associations with musculoskeletal health, adiposity, and physical functioning in high- and low-income representative samples. Indeed, low-income settings are characterised by higher prevalence of obesity (Shisana et al., 2014), and non-communicable diseases (Mayosi et al., 2009), compared to high-income settings. Additionally, South African older adults have higher prevalence of multimorbidity (65%) (Stubbs et al., 2018), defined as living with two or more chronic medical conditions, compared to their Scottish counterpart (44%) (Salman & Sellami, 2019).

6.3 Conclusions and implications

This thesis presented results highlight the need to encourage older people to be physically active, and where possible, to do so at moderate- to vigorous-intensities so that the rate of age-related changes in musculoskeletal health, body composition, and functionality is less pronounced. Age-related changes, dictated by a more cautious walking approach and increased neuromuscular capacity, were found in high-functioning Scottish older adults. These findings suggest that changes in walking might be even more pronounced in physically inactive individuals. Consequently, older adults who are less active would have the most to gain from being physically active, not only in terms of their general health and wellbeing but also for neuromuscular function and gait

Among the evidence gaps highlighted in Chapter 1, there was limited information on how sedentary time and sleep modify the beneficial effects associated with PA on musculoskeletal health, adiposity, and physical functioning in older adults. Previous research estimated dose-response associations between MVPA and SB independently, however time spent in one movement behaviour influences the time that remains to be spent in the other. Thus, it is important to account for the finite nature of a day (24-hours). This thesis has demonstrated the importance of exploring 24-h movement behaviours in older adults from differing settings - to gain a greater understanding of how these link to certain health outcomes and to understand how best to intervene where appropriate. The novelty of this thesis lies also in the comparison of communities with different socioeconomic profiles. Indeed, most of the existing studies are based on research almost exclusively from HICs. However, previous evidence highlighted the importance of considering economical, societal, and cultural diversities between HICs and LMICs in the evaluation and monitoring of 24-h movement behaviours.

A series of global plan were launched in recent years. In 2015, the United Nations adopted Sustainable Development Goals (SDGs). Specifically, health has a central role in SDG 3, aiming to ensure healthy lives and promote well-being for all (United Nations, 2015). In 2018, the WHO launched a global action plan aiming to achieve the targeted 10% reduction of global physical inactivity (World Health Organisation, 2018). Therefore, as part of the plan, in November 2020 they released updated movement behaviours recommendations. Concurrently, the International Society for Physical Activity and Health published a document on the 8 best investments for PA. It provides an overview of best evidence which can be used to advocate, inform PA policy (International Society for Physical Activity and Health, 2020). PA and SB guidelines are provided according to age groups and most recently, for people living with chronic conditions and disability (Bull et al., 2020). However, impact of socioeconomic factors on PA are not included in the action plan. Our results support the need to consider socioeconomic profile and context of targeted populations. It could be difficult to enhance PA engagement and equality with a universal approach. Thus, typical activities and their related effect of health outcomes should be considered. For example, in this thesis, differences in musculoskeletal and body composition outcomes were found. Specifically, in South African older adults' high volume of PA (MVPA) was beneficial for BMD at hip level and physical functioning (gait speed, agility and dynamic balance, aerobic endurance, and lower body strength). At the same time, the detrimental effect of SB on adiposity outcomes has been demonstrated older adults living in urban low-income settings. Conversely, the movement behaviour consistently leading to better health outcomes in the Scottish high-income group was MVPA. Indeed, older adults engaging in high volume of MVPA had better muscle mass, muscle strength, and lower adiposity levels. Thus, our results suggest that MVPA and SB have different effects and associations according to the sociodemographic profile of the populations. Consequently, movement behaviours recommendations should be adapted to fit different socioeconomic contexts to improve health inequalities.

References

Abegunde, D. O., Mathers, C. D., Adam, T., Ortegon, M., & Strong, K. (2007). The burden and costs of chronic diseases in low-income and middle-income countries. *The Lancet*, 370(9603), 1929-1938.

Aboutorabi, A., Arazpour, M., Bahramizadeh, M., Hutchins, S. W., & Fadayevatan, R. (2016). The effect of aging on gait parameters in able-bodied older subjects: a literature review*. Aging clinical and experimental research*, 28(3), 393-405.

Adamo, K. B., Prince, S. A., Tricco, A. C., Connor-Gorber, S. A. R. A. H., & Tremblay, M. (2009). A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: a systematic review. International Journal of Pediatric Obesity, 4(1), 2-27.

Adams, J. (2006). Socioeconomic position and sleep quantity in UK adults. *Journal of Epidemiology & Community Health*, 60(3), 267-269.

Adler, N. E., Boyce, T., Chesney, M. A., Cohen, S., Folkman, S., Kahn, R. L., & Syme, S. L. (1994). Socioeconomic status and health: the challenge of the gradient. *American psychologist*, 49(1), 15.

Aggio, D. A., Sartini, C., Papacosta, O., Lennon, L. T., Ash, S., Whincup, P. H., ... & Jefferis, B. J. (2016). Cross-sectional associations of objectively measured physical activity and sedentary time with sarcopenia and sarcopenic obesity in older men. *Preventive medicine*, 91, 264-272.

Agyemang, C., Boatemaa, S., Frempong, G. A., & Aikins, A. (2016). Obesity in sub-Saharan Africa. *Metabolic syndrome. Switzerland: Springer International Publishing*, 1-13.

Alaba, O., & Chola, L. (2014). Socioeconomic inequalities in adult obesity prevalence in South Africa: a decomposition analysis. International journal of environmental research and public health, 11(3), 3387-3406.

Allison, S. J., Folland, J. P., Rennie, W. J., Summers, G. D., & Brooke-Wavell, K. (2013). High impact exercise increased femoral neck bone mineral density in older men: a randomised unilateral intervention. Bone, 53(2), 321-328.

Aloba, O. O., Adewuya, A. O., Ola, B. A., & Mapayi, B. M. (2007). Validity of the Pittsburgh sleep quality index (PSQI) among Nigerian university students. *Sleep medicine*, 8(3), 266-270.

Althoff, T., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature*, *547*(7663), 336-339.

Alva, M. D. C. V., Camacho, M. E. I., Velázquez, J. D., & Lazarevich, I. (2013). The relationship between sarcopenia, undernutrition, physical mobility and basic activities of daily living in a group of elderly women of Mexico City. *Nutricion hospitalaria*, *28*(2), 514-521.

Ameye, H., & Swinnen, J. (2019). Obesity, income and gender: the changing global relationship. Global Food Security, 23, 267-281.

Anton, S. D., Woods, A. J., Ashizawa, T., Barb, D., Buford, T. W., Carter, C. S., ... & Pahor, M. (2015). Successful aging: advancing the science of physical independence in older adults. *Ageing research reviews*, 24, 304-327.

Artaud, F., Singh-Manoux, A., Dugravot, A., Tzourio, C., & Elbaz, A. (2015). Decline in fast gait speed as a predictor of disability in older adults. *Journal of the American Geriatrics Society*, 63(6), 1129-1136.

Asp, M., Simonsson, B., Larm, P., & Molarius, A. (2017). Physical mobility, physical activity, and obesity among elderly: findings from a large population-based Swedish survey. *Public health*, *147*, 84-91.

Atkin, A. J., Gorely, T., Clemes, S. A., Yates, T., Edwardson, C., Brage, S., ... & Biddle, S. J. (2012). Methods of measurement in epidemiology: sedentary behaviour. *International journal of epidemiology*, *41*(5), 1460-1471.

Bacaro, V., Ballesio, A., Cerolini, S., Vacca, M., Poggiogalle, E., Donini, L. M., ... & Lombardo, C. (2020). Sleep duration and obesity in adulthood: an updated systematic review and meta-analysis. *Obesity Research & Clinical Practice.*

Bailey, C. A., Corona, F., Pilloni, G., Porta, M., Fastame, M. C., Hitchcott, P. K., ... & Côté, J. N. (2018). Sex-dependent and sex-independent muscle activation patterns in adult gait as a function of age. *Experimental Gerontology*, 110, 1-8.

Bailey, C. A., Porta, M., Pilloni, G., Arippa, F., Pau, M., & Côté, J. N. (2019). Sex-independent and dependent effects of older age on cycle-to-cycle variability of muscle activation during gait. *Experimental gerontology*, 124, 110656.

Baker, E. H. (2014). Socioeconomic status, definition. *The Wiley Blackwell encyclopedia of health, illness, behaviour, and society*, 2210-2214.

Barone Gibbs, B., Brach, J. S., Byard, T., Creasy, S., Davis, K. K., McCoy, S., ... & Jakicic, J. M. (2017). Reducing sedentary behavior versus increasing moderate-to-vigorous intensity physical activity in older adults: a 12-week randomized, clinical trial. Journal of aging and health, 29(2), 247-267.

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., & Cerin, E. (2017). Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *International journal of behavioural nutrition and physical activity*, 14(1), 1-24.

Barr, A. L., Partap, U., Young, E. H., Agoudavi, K., Balde, N., Kagaruki, G. B., . . . Sandhu, M. S. (2020). Sociodemographic inequities associated with participation in leisure-time physical activity in sub-Saharan Africa: an individual participant data meta-analysis. *BMC Public Health*, 20(1), 927.

Baum, J. I., & Wolfe, R. R. (2015, September). The link between dietary protein intake, skeletal muscle function and health in older adults. In Healthcare (Vol. 3, No. 3, pp. 529-543). Multidisciplinary Digital Publishing Institute.

Bauman, A. E., Petersen, C. B., Blond, K., Rangul, V., & Hardy, L. L. (2018). The descriptive epidemiology of sedentary behaviour. In *Sedentary behaviour epidemiology* (pp. 73-106). Springer, Cham.

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., & Martin, B. W. (2012). Correlates of physical activity: why are some people physically active and others not? *The Lancet, 380*(9838), 258-271.

Bauman, A., Merom, D., Bull, F. C., Buchner, D. M., & Fiatarone Singh, M. A. (2016). Updating the evidence for physical activity: summative reviews of the epidemiological evidence, prevalence, and interventions to promote "active aging". *The gerontologist*, 56(Suppl_2), S268-S280.

Beauchet, O., Allali, G., Sekhon, H., Verghese, J., Guilain, S., Steinmetz, J. P., ... & Helbostad, J. L. (2017). Guidelines for assessment of gait and reference values for spatiotemporal gait parameters in older adults: the biomathics and Canadian gait consortiums initiative. *Frontiers in human neuroscience*, 11, 353.

Beaufrere, B., & Morio, B. (2000). Fat and protein redistribution with aging: metabolic considerations. *European journal of clinical nutrition*, *54*(3), S48-S53.

Beck, B. R., Daly, R. M., Singh, M. A. F., & Taaffe, D. R. (2017). Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis. *Journal of science and medicine in sport*, *20*(5), 438-445.

Beenackers, M. A., Kamphuis, C. B., Giskes, K., Brug, J., Kunst, A. E., Burdorf, A., & Van Lenthe, F. J. (2012). Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *International journal of behavioural nutrition and physical activity*, *9*(1), 1-23.

Beenackers, M. A., Kamphuis, C. B., Giskes, K., Brug, J., Kunst, A. E., Burdorf, A., & Van Lenthe, F. J. (2012). Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *International journal of behavioural nutrition and physical activity*, 9(1), 1-23.

Belza, B., Walwick, J., Schwartz, S., LoGerfo, J., Shiu-Thornton, S., & Taylor, M. (2004). pEER REvIEWED: older Adult perspectives on physical Activity and Exercise: voices From Multiple cultures. Preventing chronic disease, 1(4).

Berard, A., Bravo, G., & Gauthier, P. (1997). Meta-analysis of the effectiveness of physical activity for the prevention of bone loss in postmenopausal women. *Osteoporosis international*, *7*(4), 331-337.

Bevilacqua, G., Denison, H. J., Laskou, F., Jameson, K. A., Ward, K. A., Cooper, C., & Dennison, E. M. (2020). Self-reported Sleep Quality and Bone Outcomes in Older Adults: Findings from the Hertfordshire Cohort Study. *Calcified tissue international*, 1-10.

Biddle, S., Cavill, N., Ekelund, U., Gorely, T., Griffiths, M., Jago, R., ... & Richardson, D. (2010). Sedentary behaviour and obesity: review of the current scientific evidence.

Bohannon, R. W. (2019). Grip strength: an indispensable biomarker for older adults. *Clinical interventions in aging*, 14, 1681.

Bouchard, D. R., Dionne, I. J., & Brochu, M. (2009). Sarcopenic/obesity and physical capacity in older men and women: data from the Nutrition as a Determinant of Successful Aging (NuAge)—the Quebec Longitudinal Study. *Obesity*, *17*(11), 2082-2088.

Bowling, A., & Dieppe, P. (2005). What is successful ageing and who should define it?. *Bmj*, *331*(7531), 1548-1551.

Boyer, K. A., Andriacchi, T. P., & Beaupre, G. S. (2012). The role of physical activity in changes in walking mechanics with age. *Gait & posture*, 36(1), 149-153.

Brach, J. S., & VanSwearingen, J. M. (2013). Interventions to improve walking in older adults. *Current translational geriatrics and experimental gerontology reports*, 2(4), 230-238.

Bridenbaugh, S. A., & Kressig, R. W. (2011). Laboratory review: the role of gait analysis in seniors' mobility and fall prevention. Gerontology, 57(3), 256-264.

Briggs, A. M., Cross, M. J., Hoy, D. G., Sanchez-Riera, L., Blyth, F. M., Woolf, A. D., & March, L. (2016). Musculoskeletal health conditions represent a global threat to healthy aging: a report for the 2015 World Health Organization world report on ageing and health. *The Gerontologist*, 56(suppl_2), S243-S255.

Briggs, A. M., Cross, M. J., Hoy, D. G., Sanchez-Riera, L., Blyth, F. M., Woolf, A. D., & March, L. (2016). Musculoskeletal health conditions represent a global threat to healthy aging: a report for the 2015 World Health Organization world report on ageing and health. The Gerontologist, 56(suppl_2), S243-S255.

Brook, R. D., Appel, L. J., Rubenfire, M., Ogedegbe, G., Bisognano, J. D., Elliott, W. J., Fuchs, F. D., Hughes, J. W., Lackland, D. T., Staffileno, B. A., Townsend, R. R., Rajagopalan, S., & American Heart Association Professional Education Committee of the Council for High Blood Pressure Research, Council on Cardiovascular and Stroke Nursing, Council on Epidemiology and Prevention, and Council on Nutrition, Physical Activity (2013). Beyond medications and diet: alternative approaches to lowering blood pressure: a scientific statement from the american heart association. *Hypertension (Dallas, Tex. : 1979)*, *61*(6), 1360–1383.

Brown, C. (2017). Staying strong. Nature, 550(7674), S15-S17.

Browning, C. R., & Cagney, K. A. (2003). Moving beyond poverty: neighborhood structure, social processes, and health. Journal of health and social behaviour, 552-571.

Bruyère, O., Beaudart, C., Ethgen, O., Reginster, J. Y., & Locquet, M. (2019). The health economics burden of sarcopenia: a systematic review. Maturitas, 119, 61-69.

Buchmann, N., Spira, D., Norman, K., Demuth, I., Eckardt, R., & Steinhagen-Thiessen, E. (2016). Sleep, muscle mass and muscle function in older people: a cross-sectional analysis based on data from the Berlin Aging Study II (BASE-II*). Deutsches Ärzteblatt international*, 113(15), 253.

Buchner, D. M., & de Lateur, B. J. (1991). The importance of skeletal muscle strength to physical function in older adults. *Annals of Behavioural Medicine*, 13(3), 91-98.

Buchner, D. M., Cress, M. E., Esselman, P. C., Margherita, A. J., De Lateur, B. J., Campbell, A. J., & Wagner, E. H. (1996). Factors associated with changes in gait speed in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 51(6), M297-M302.

Buford, T. W., Anton, S. D., Judge, A. R., Marzetti, E., Wohlgemuth, S. E., Carter, C. S., Leeuwenburgh, C., Pahor, M., & Manini, T. M. (2010). Models of accelerated sarcopenia: critical pieces for solving the puzzle of age-related muscle atrophy. *Ageing research reviews*, 9(4), 369–383.

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., ... & Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine*, 54(24), 1451-1462.

Buman, M. P., Hekler, E. B., Haskell, W. L., Pruitt, L., Conway, T. L., Cain, K. L., ... & King, A. C. (2010). Objective light-intensity physical activity associations with rated health in older adults. *American journal of epidemiology*, *172*(10), 1155-1165.

Buysse, D. J., Reynolds III, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry research*, 28(2), 193-213.

Campbell, M., Varley-Campbell, J., Fulford, J., Taylor, B., Mileva, K. N., & Bowtell, J. L. (2019). Effect of immobilisation on neuromuscular function in vivo in humans: a systematic review. *Sports Medicine*, *49*(6), 931-950.

Capistrant, B. D., Glymour, M. M., & Berkman, L. F. (2014). Assessing mobility difficulties for cross-national comparisons: results from the World Health Organization Study on Global AGEing and Adult Health. *Journal of the American Geriatrics Society*, 62(2), 329-335.

Cappellini, G., Ivanenko, Y. P., Poppele, R. E., & Lacquaniti, F. (2006). Motor patterns in human walking and running. Journal of neurophysiology, 95(6), 3426-3437.

Caspersen, C. J., Powell, K. E., and Christenson, G. M. (1985). Physical activity, exercise and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* 100, 126–131.

Celis-Morales, C. A., Perez-Bravo, F., Ibañez, L., Salas, C., Bailey, M. E., & Gill, J. M. (2012). Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. *PloS one*, 7(5), e36345.

Cerin, E., & Leslie, E. (2008). How socio-economic status contributes to participation in leisure-time physical activity. *Social science & medicine*, *66*(12), 2596-2609.

Cerin, E., Nathan, A., Van Cauwenberg, J., Barnett, D. W., & Barnett, A. (2017). The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *International journal of behavioural nutrition and physical activity*, 14(1), 1-23.

Chantler, S., Dickie, K., Goedecke, J. H., Levitt, N. S., Lambert, E. V., Evans, J., ... & Micklesfield, L. K. (2012). Site-specific differences in bone mineral density in black and white premenopausal South African women. *Osteoporosis International*, 23(2), 533-542.

Chaput, J. P., Carson, V., Gray, C. E., & Tremblay, M. S. (2014). Importance of all movement behaviours in a 24-hour period for overall health. *International journal of environmental research and public health*, 11(12), 12575-12581.

Chaput, J. P., Dutil, C., & Sampasa-Kanyinga, H. (2018). Sleeping hours: what is the ideal number and how does age impact this?. *Nature and science of sleep*, 10, 421.

Chaput, J. P., Dutil, C., Featherstone, R., Ross, R., Giangregorio, L., Saunders, T. J., ... & Carrier, J. (2020). Sleep duration and health in adults: an overview of systematic reviews. *Applied Physiology, Nutrition, and Metabolism*, *45*(10), S218-S231.

Chastin, S. F. M., Ferriolli, E., Stephens, N. A., Fearon, K. C., & Greig, C. (2012). Relationship between sedentary behaviour, physical activity, muscle quality and body composition in healthy older adults. *Age and ageing*, *41*(1), 111-114.

Chastin, S. F. M., Van Cauwenberg, J., Maenhout, L., Cardon, G., Lambert, E. V., & Van Dyck, D. (2020). Inequality in physical activity, global trends by income inequality and gender in adults. *International Journal of Behavioural Nutrition and Physical Activity*, 17(1), 1-8.

Chastin, S. F., Buck, C., Freiberger, E., Murphy, M., Brug, J., Cardon, G., ... & Oppert, J. M. (2015). Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. *International Journal of Behavioural Nutrition and Physical Activity*, 12(1), 1-12.

Chastin, S. F., Mandrichenko, O., Helbostadt, J. L., & Skelton, D. A. (2014). Associations between objectively-measured sedentary behaviour and physical activity with bone mineral density in adults and older adults, the NHANES study. *Bone*, 64, 254-262.

Chastin, S. F., Palarea-Albaladejo, J., Dontje, M. L., & Skelton, D. A. (2015). Combined Effects of Time Spent in Physical Activity, Sedentary Behaviours and Sleep on Obesity and Cardio-

Metabolic Health Markers: A Novel Compositional Data Analysis Approach. *PLoS One*, 10(10), e0139984.

Chastin, S., Gardiner, P. A., Harvey, J. A., Leask, C. F., Jerez-Roig, J., Rosenberg, D., ... & Skelton, D. A. (2021). Interventions for reducing sedentary behaviour in community-dwelling older adults. Cochrane Database of Systematic Reviews, (6).

Chaudhury, H., Campo, M., Michael, Y., & Mahmood, A. (2016). Neighbourhood environment and physical activity in older adults. *Social science & medicine*, 149, 104-113.

Chen, H. C., Hsu, N. W., & Chou, P. (2017). The association between sleep duration and hand grip strength in community-dwelling older adults: the Yilan study, Taiwan. *Sleep*, 40(4).

Chien, M. Y., Wang, L. Y., & Chen, H. C. (2015). The relationship of sleep duration with obesity and sarcopenia in community-dwelling older adults. *Gerontology*, *61*(5), 399-406.

Cho, B. Y., Seo, D. C., Lin, H. C., Lohrmann, D. K., & Chomistek, A. K. (2018). BMI and central obesity with falls among community-dwelling older adults. *American journal of preventive medicine*, *54*(4), e59-e66.

Chou, C. H., Hwang, C. L., & Wu, Y. T. (2012). Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. Archives of physical medicine and rehabilitation, 93(2), 237-244.

Chow, C. M., Wong, S. N., Shin, M., Maddox, R. G., Feilds, K. L., Paxton, K., ... & Steinbeck, K. (2016). Defining the rest interval associated with the main sleep period in actigraph scoring. *Nature and science of sleep*, 8, 321.

Christos, K. F., Maria, P. E., Ioanna, P. V., Polina, P., Ioannis, K., Sofia, D., ... & Lamprini, K. (2015). Smoking is associated with osteoporosis development in Primary care population. *Am J Nurs*, *4*, 96-101.

Chung, M. J., & Wang, M. J. J. (2010). The change of gait parameters during walking at different percentage of preferred walking speed for healthy adults aged 20–60 years. *Gait & posture*, 31(1), 131-135.

Ciprandi, D., Bertozzi, F., Zago, M., Ferreira, C. L. P., Boari, G., Sforza, C., & Galvani, C. (2017). Study of the association between gait variability and physical activity. European review of aging and physical activity, 14(1), 1-10.

Clark, B., & Sugiyama, T. (2015). Prevalence, trends, and correlates of sedentary behavior. In Physical activity, exercise, sedentary behavior and health (pp. 79-90). Springer, Tokyo.

Clark, B. C. (2019). Neuromuscular changes with aging and sarcopenia. *The Journal of frailty & aging*, 8(1), 7-9.

Cleland, C., Reis, R. S., Ferreira Hino, A. A., Hunter, R., Fermino, R. C., Koller de Paiva, H., ... & Ellis, G. (2019). Built environment correlates of physical activity and sedentary behaviour in older adults: A comparative review between high and low-middle income countries. *Health Place*, *57*, 277-304.

Colón-Emeric, C. S., Whitson, H. E., Pavon, J., & Hoenig, H. (2013). Functional decline in older adults. *American family physician*, *88*(6), 388–394.

Cooper, A. J., Simmons, R. K., Kuh, D., Brage, S., Cooper, R., & NSHD scientific and data collection team (2015). Physical activity, sedentary time and physical capability in early old age: British birth cohort study. *PloS one*, 10(5), e0126465.

Copeland, J. L., Ashe, M. C., Biddle, S. J., Brown, W. J., Buman, M. P., Chastin, S., ... & Dogra, S. (2017). Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. *British journal of sports medicine*, 51(21), 1539-1539.

Craig, J., Murray, A., Mitchell, S., Clark, S., Saunders, L., & Burleigh, L. (2013). The high cost to health and social care of managing falls in older adults living in the community in Scotland. *Scottish Medical Journal*, 58(4), 198–203.

Crombie, I. K., Irvine, L., Williams, B., McGinnis, A. R., Slane, P. W., Alder, E. M., & McMurdo, M. E. (2004). Why older people do not participate in leisure time physical activity: a survey of activity levels, beliefs and deterrents. *Age and ageing*, 33(3), 287-292.

Crowley, K. (2011). Sleep and sleep disorders in older adults. *Neuropsychology review*, 21(1), 41-53.

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., ... & Zamboni, M. (2019). Sarcopenia: revised European consensus on definition and diagnosis. *Age and ageing*, 48(1), 16-31.

Cuoco, A., Callahan, D. M., Sayers, S., Frontera, W. R., Bean, J., & Fielding, R. A. (2004). Impact of muscle power and force on gait speed in disabled older men and women. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 59(11), 1200-1206.

Curtis, E., Litwic, A., Cooper, C., & Dennison, E. (2015). Determinants of Muscle and Bone Aging. *Journal of cellular physiology*, 230(11), 2618–2625.

Da Silva Costa, A. A., Moraes, R., Hortobágyi, T., & Sawers, A. (2020). Older adults reduce the complexity and efficiency of neuromuscular control to preserve walking balance. *Experimental gerontology*, 140, 111050.

de Souto Barreto, P., Ferrandez, A. M., & Saliba-Serre, B. (2013). Are older adults who volunteer to participate in an exercise study fitter and healthier than nonvolunteers? The participation bias of the study population. Journal of Physical Activity and Health, 10(3), 359-367.

Decaria, J. E., Sharp, C., & Petrella, R. J. (2012). Scoping review report: obesity in older adults. *International journal of obesity*, *36*(9), 1141-1150.

Dempsey, P. C., Biddle, S. J., Buman, M. P., Chastin, S., Ekelund, U., Friedenreich, C. M., ... & Bull, F. (2020). New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. *International Journal of Behavioural Nutrition and Physical Activity*, 17(1), 1-12.Dishman, R. K., Washburn, R. A., & Schoeller, D. A. (2001). Measurement of physical activity. Quest, 53(3), 295-309.

Distefano, G., & Goodpaster, B. H. (2018). Effects of Exercise and Aging on Skeletal Muscle. *Cold Spring Harbor perspectives in medicine*, *8*(3), a029785.

Dixon, J. B. (2010). The effect of obesity on health outcomes. *Molecular and cellular endocrinology*, 316(2), 104-108.

Dixon, P. C., Schütte, K. H., Vanwanseele, B., Jacobs, J. V., Dennerlein, J. T., & Schiffman, J. M. (2018). Gait adaptations of older adults on an uneven brick surface can be predicted by age-related physiological changes in strength. *Gait & posture*, 61, 257-262.

Doak, C. M., Wijnhoven, T. M. A., Schokker, D. F., Visscher, T. L. S., & Seidell, J. C. (2012). Age standardization in mapping adult overweight and obesity trends in the WHO European Region. *Obesity reviews*, *13*(2), 174-191.

Draper, C. E., Tomaz, S. A., Biersteker, L., Cook, C. J., Couper, J., De Milander, M., ... & Okely, A. D. (2020). The South African 24-hour movement guidelines for birth to 5 years: an integration of physical activity, sitting behaviour, screen time, and sleep. *Journal of Physical Activity and Health*, 17(1), 109-119.

Dumuid, D., Lewis, L. K., Olds, T. S., Maher, C., Bondarenko, C., & Norton, L. (2018). Relationships between older adults' use of time and cardio-respiratory fitness, obesity and cardio-metabolic risk: a compositional isotemporal substitution analysis. *Maturitas*, *110*, 104-110.

Duncan, M. J., Rowlands, A., Lawson, C., Leddington Wright, S., Hill, M., Morris, M., ... & Tallis, J. (2020). Using accelerometry to classify physical activity intensity in older adults: What is the optimal wear-site?. *European journal of sport science*, 20(8), 1131-1139.

Duncan, R. P., Combs-Miller, S. A., McNeely, M. E., Leddy, A. L., Cavanaugh, J. T., Dibble, L. E., ... & Earhart, G. M. (2017). Are the average gait speeds during the 10 meter and 6 minute walk tests redundant in Parkinson disease?. *Gait & posture*, *52*, 178-182.

Edwards, M. H., Dennison, E. M., Sayer, A. A., Fielding, R., & Cooper, C. (2015). Osteoporosis and sarcopenia in older age. Bone, 80, 126-130.

Edwardson, C. L., Winkler, E. A., Bodicoat, D. H., Yates, T., Davies, M. J., Dunstan, D. W., & Healy, G. N. (2017). Considerations when using the activPAL monitor in field-based research with adult populations. *Journal of sport and health science*, *6*(2), 162-178.

Egerton, T., Paterson, K., & Helbostad, J. L. (2017). The association between gait characteristics and ambulatory physical activity in older people: a cross-sectional and longitudinal observational study using generation 100 data. Journal of aging and physical activity, 25(1), 10-19.

Egerton, T., Hokstad, A., Askim, T., Bernhardt, J., & Indredavik, B. (2015). Prevalence of fatigue in patients 3 months after stroke and association with early motor activity: a prospective study comparing stroke patients with a matched general population cohort*. BMC neurology*, 15(1), 1-9.

Elhadi, M. M., Ma, C. Z., Wong, D. W., Wan, A. H., & Lee, W. C. (2017). Comprehensive gait analysis of healthy older adults who have undergone long-distance walking. Journal of aging and physical activity, 25(3), 367-377.

Elshahat, S., O'Rorke, M., & Adlakha, D. (2020). Built environment correlates of physical activity in low-and middle-income countries: A systematic review. *PloS one*, *15*(3), e0230454.

Evenson, K. R., Wen, F., Metzger, J. S., & Herring, A. H. (2015). Physical activity and sedentary behaviour patterns using accelerometry from a national sample of United States adults. *International Journal of Behavioural Nutrition and Physical Activity*, *12*(1), 1-13.

Evitt, C. P., & Quigley, P. A. (2004). Fear of falling in older adults: a guide to its prevalence, risk factors, and consequences. *Rehabilitation Nursing*, 29(6), 207.

Farrahi, V., Kangas, M., Walmsley, R., Niemelä, M., Kiviniemi, A., Puukka, K., ... & Jämsä, T. (2021). Compositional associations of sleep and activities within the 24-H cycle with

Cardiometabolic health markers in adults. *Medicine and Science in Sports and Exercise*, 53(2), 324.

Faubel, R., Lopez-Garcia, E., Guallar-Castillón, P., Balboa-Castillo, T., Gutiérrez-Fisac, J. L., Banegas, J. R., & Rodríguez-Artalejo, F. (2009). Sleep duration and health-related quality of life among older adults: a population-based cohort in Spain. *Sleep*, *32*(8), 1059-1068.

Fielding, R. A., Guralnik, J. M., King, A. C., Pahor, M., McDermott, M. M., Tudor-Locke, C., ... & LIFE study group. (2017). Dose of physical activity, physical functioning and disability risk in mobility-limited older adults: Results from the LIFE study randomized trial. *PloS one*, *12*(8), e0182155.

Fontaine, K. R., Redden, D. T., Wang, C., Westfall, A. O., & Allison, D. B. (2003). Years of life lost due to obesity. *Jama*, 289(2), 187-193.

Foong, Y. C., Chherawala, N., Aitken, D., Scott, D., Winzenberg, T., & Jones, G. (2016). Accelerometer-determined physical activity, muscle mass, and leg strength in community-dwelling older adults. *Journal of cachexia, sarcopenia and muscle*, 7(3), 275-283.

Ford, N. D., Patel, S. A., & Narayan, K. V. (2017). Obesity in low-and middle-income countries: burden, drivers, and emerging challenges. *Annual review of public health*, 38, 145-164.

Fragala, M. S., Cadore, E. L., Dorgo, S., Izquierdo, M., Kraemer, W. J., Peterson, M. D., & Ryan, E. D. (2019). Resistance training for older adults: position statement from the national strength and conditioning association. *The Journal of Strength & Conditioning Research*, 33(8).

Frost, H. M. (1988). Structural adaptations to mechanical usage. A proposed “three-way rule” for bone modeling. *Veterinary and Comparative Orthopaedics and Traumatology*, *1*(02), 80-85.

Fu, X., Zhao, X., Lu, H., Jiang, F., Ma, X., & Zhu, S. (2011). Association between sleep duration and bone mineral density in Chinese women. *Bone*, 49(5), 1062-1066.

Füzéki, E., & Banzer, W. (2018). Physical Activity Recommendations for Health and Beyond in Currently Inactive Populations. *International journal of environmental research and public health*, *15*(5), 1042.

Gába, A., & Přidalová, M. (2014). Age-related changes in body composition in a sample of Czech women aged 18–89 years: a cross-sectional study. *European journal of nutrition*, *53*(1), 167-176.

Gába, A., Pelclová, J., Štefelová, N., Přidalová, M., Zając-Gawlak, I., Tlučáková, L., ... & Svozilová, Z. (2021). Prospective study on sedentary behaviour patterns and changes in body composition parameters in older women: a compositional and isotemporal substitution analysis. *Clinical Nutrition*, *40*(4), 2301-2307.

Gadie, A., Shafto, M., Leng, Y., Kievit, R. A., & Cam, C. A. N. (2017). How are age-related differences in sleep quality associated with health outcomes? An epidemiological investigation in a UK cohort of 2406 adults. *BMJ Open*, 7(7), e014920.

Gale, C. R., Cooper, C., & Aihie Sayer, A. (2014). Prevalence of frailty and disability: findings from the English Longitudinal Study of Ageing. *Age and ageing*, 44(1), 162-165.

Garcia Meneguci, C. A., Meneguci, J., Sasaki, J. E., Tribess, S., & Júnior, J. S. V. (2021). Physical activity, sedentary behaviour and functionality in older adults: A cross-sectional path analysis. *PLoS one*, 16(1), e0246275.

Gaskin, C. J., & Orellana, L. (2018). Factors associated with physical activity and sedentary behaviour in older adults from six low-and middle-income countries. *International journal of environmental research and public health*, *15*(5), 908.

Ghazwan, A., Forrest, S. M., Holt, C. A., & Whatling, G. M. (2017). Can activities of daily living contribute to EMG normalization for gait analysis?. *PLoS One*, 12(4), e0174670.

Gianoudis, J., Bailey, C. A., & Daly, R. M. (2015). Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. *Osteoporosis International*, *26*(2), 571-579.

Gidlow, C., Johnston, L. H., Crone, D., Ellis, N., & James, D. (2006). A systematic review of the relationship between socio-economic position and physical activity. *Health Education Journal*, 65(4), 338-367.

Gildner, T. E., Liebert, M. A., Kowal, P., Chatterji, S., & Josh Snodgrass, J. (2014). Sleep duration, sleep quality, and obesity risk among older adults from six middle-income countries: Findings from the study on global AGEing and adult health (SAGE). *American Journal of Human Biology*, *26*(6), 803-812.

Giles, T. D., Materson, B. J., Cohn, J. N., & Kostis, J. B. (2009). Definition and classification of hypertension: an update. *The journal of clinical hypertension*, *11*(11), 611-614.

Gobbo, L. A., Júdice, P. B., Hetherington-Rauth, M., Sardinha, L. B., & Dos Santos, V. R. (2020). Sedentary Patterns Are Associated with Bone Mineral Density and Physical Function in Older Adults: Cross-Sectional and Prospective Data. *International Journal of Environmental Research and Public Health*, 17(21), 8198.

Godde, B., & Voelcker-Rehage, C. (2017). Cognitive resources necessary for motor control in older adults are reduced by walking and coordination training. *Frontiers in human neuroscience*, 11, 156.

Gómez-Cabello, A., Pedrero-Chamizo, R., Olivares, P. R., Hernández-Perera, R., Rodríguez-Marroyo, J. A., Mata, E., ... & EXERNET Study Group. (2012). Sitting time increases the overweight and obesity risk independently of walking time in elderly people from Spain. *Maturitas*, *73*(4), 337-343.

Gómez-Olivé, F. X., Thorogood, M., Kandala, N. B., Tigbe, W., Kahn, K., Tollman, S., & Stranges, S. (2014). Sleep problems and mortality in rural South Africa: novel evidence from a low-resource setting. *Sleep medicine*, 15(1), 56-63.

González, K., Fuentes, J., & Márquez, J. L. (2017). Physical inactivity, sedentary behaviour and chronic diseases. *Korean journal of family medicine*, *38*(3), 111.

Goodpaster, B. H., Chomentowski, P., Ward, B. K., Rossi, A., Glynn, N. W., Delmonico, M. J., ... & Newman, A. B. (2008). Effects of physical activity on strength and skeletal muscle fat infiltration in older adults: a randomized controlled trial. Journal of applied physiology, 105(5), 1498-1503.

Gooneratne, N. S., & Vitiello, M. V. (2014). Sleep in older adults: normative changes, sleep disorders, and treatment options. *Clinics in geriatric medicine*, 30(3), 591-627.

Gottlieb, D. J., Redline, S., Nieto, F. J., Baldwin, C. M., Newman, A. B., Resnick, H. E., & Punjabi, N. M. (2006). Association of usual sleep duration with hypertension: the Sleep Heart Health Study. *Sleep*, 29(8), 1009-1014.

Gouda, H. N., Charlson, F., Sorsdahl, K., Ahmadzada, S., Ferrari, A. J., Erskine, H., ... & Whiteford, H. (2019). Burden of non-communicable diseases in sub-Saharan Africa, 1990–2017: results from the Global Burden of Disease Study 2017. *The Lancet Global Health*, *7*(10), e1375-e1387.

Gradidge, P. J. L., Crowther, N. J., Chirwa, E. D., Norris, S. A., & Micklesfield, L. K. (2014). Patterns, levels and correlates of self-reported physical activity in urban black Soweto women. *BMC Public Health*, 14(1), 1-10.

Grandner, M. A., Patel, N. P., Gehrman, P. R., Xie, D., Sha, D., Weaver, T., & Gooneratne, N. (2010). Who gets the best sleep? Ethnic and socioeconomic factors related to sleep complaints. *Sleep medicine*, 11(5), 470-478.

Greco, E. A., Lenzi, A., & Migliaccio, S. (2015). The obesity of bone. *Therapeutic advances in endocrinology and metabolism*, *6*(6), 273-286.

Grgic, J., Dumuid, D., Bengoechea, E. G., Shrestha, N., Bauman, A., Olds, T., & Pedisic, Z. (2018). Health outcomes associated with reallocations of time between sleep, sedentary behaviour, and physical activity: a systematic scoping review of isotemporal substitution studies. *International Journal of Behavioural Nutrition and Physical Activity*, 15(1), 1-68.

Groenendijk, I., den Boeft, L., van Loon, L. J., & de Groot, L. C. (2019). High versus low dietary protein intake and bone health in older adults: a systematic review and meta-analysis. Computational and structural biotechnology journal, 17, 1101-1112.

Gundersen, C., & Ziliak, J. P. (2015). Food insecurity and health outcomes. *Health affairs*, *34*(11), 1830-1839.

Gupta, N., Dumuid, D., Korshøj, M., Jørgensen, M. B., Søgaard, K., & Holtermann, A. (2018). Is daily composition of movement behaviours related to blood pressure in working adults?. *Medicine and science in sports and exercise*, *50*(10), 2150-2155.

Gupta, N., Mathiassen, S. E., Mateu-Figueras, G., Heiden, M., Hallman, D. M., Jørgensen, M. B., & Holtermann, A. (2018). A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behaviour and physical activity. *International Journal of Behavioural Nutrition and Physical Activity*, 15(1), 1-12.

Guralnik, J. M., Ferrucci, L., Balfour, J. L., Volpato, S., & Di Iorio, A. (2001). Progressive versus catastrophic loss of the ability to walk: implications for the prevention of mobility loss. *Journal of the American Geriatrics Society*, 49(11), 1463-1470.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., ... & Wallace, R. B. (1994). A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of gerontology*, 49(2), M85-M94.

Guthold, R., Louazani, S. A., Riley, L. M., Cowan, M. J., Bovet, P., Damasceno, A., ... & Armstrong, T. P. (2011). Physical activity in 22 African countries: results from the World Health Organization STEPwise approach to chronic disease risk factor surveillance. *American journal of preventive medicine*, *41*(1), 52-60.

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *The Lancet Global Health*, 6(10), e1077-e1086.

Hahn, M. E., Lee, H. J., & Chou, L. S. (2005). Increased muscular challenge in older adults during obstructed gait. *Gait & posture*, 22(4), 356-361.

Halaweh, H., Willén, C., & Svantesson, U. (2016). Association between physical activity and physical functioning in community-dwelling older adults. *European Journal of Physiotherapy*, 19(1), 40-47.

Hallal, P. C., Matsudo, S., & Farias Jr, J. C. (2012). Measurement of physical activity by self-report in low-and middle-income countries: more of the same is not enough. Journal of Physical Activity and Health, 9(1), S88.

Hallgren, M., Dunstan, D. W., & Owen, N. (2020). Passive versus mentally active sedentary behaviours and depression. *Exercise and sport sciences reviews*, *48*(1), 20-27.
Harvey, J. A., Chastin, S. F., & Skelton, D. A. (2018). Breaking sedentary behaviour has the potential to increase/maintain function in frail older adults. *Journal of frailty, sarcopenia and falls*, *3*(1), 26.

Hamrick, M. (2010). JMNI special issue: basic science and mechanisms of muscle-bone interactions. J Musculoskelet Neuronal Interact, 10(1), 1-2.

Hanach, N. I., McCullough, F., & Avery, A. (2019). The impact of dairy protein intake on muscle mass, muscle strength, and physical performance in middle-aged to older adults with or without existing sarcopenia: A systematic review and meta-analysis. Advances in Nutrition, 10(1), 59-69.

Haysom, G., Crush, J., & Caesar, M. (2017). No. 03: The Urban Food System of Cape Town, South Africa.

Hausdroff, J. (2005). Gait variability: methods, modeling and meaning. *J NeuroEngineering Rehabil*, 20, 1-9.

Hausdorff, J. M. (2007). Gait dynamics, fractals and falls: finding meaning in the stride-to-stride fluctuations of human walking. *Human movement science*, 26(4), 555-589.

Hausdorff, J. M., Rios, D. A., & Edelberg, H. K. (2001). Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Archives of physical medicine and rehabilitation*, 82(8), 1050-1056.

He, C., He, W., Hou, J., Chen, K., Huang, M., Yang, M., ... & Li, C. (2020). Bone and Muscle Crosstalk in Aging. *Frontiers in Cell and Developmental Biology*, 8.

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

Herd, P., Goesling, B., & House, J. S. (2007). Socioeconomic Position and Health: The Differential Effects of Education versus Income on the Onset versus Progression of Health Problems. *Journal of Health and Social Behaviour*, 48(3), 223–238.

Herman, T., Giladi, N., Gurevich, T., & Hausdorff, J. M. (2005). Gait instability and fractal dynamics of older adults with a “cautious” gait: why do certain older adults walk fearfully?. *Gait & posture*, 21(2), 178-185.

Herssens, N., Verbecque, E., Hallemans, A., Vereeck, L., Van Rompaey, V., & Saeys, W. (2018). Do spatiotemporal parameters and gait variability differ across the lifespan of healthy adults? A systematic review. *Gait & Posture*, 64, 181-190.

Hill, T. D., Trinh, H. N., Wen, M., & Hale, L. (2016). Perceived neighborhood safety and sleep quality: a global analysis of six countries. *Sleep medicine*, *18*, 56-60.

Hinrichs, T., von Bonsdorff, M. B., Törmäkangas, T., von Bonsdorff, M. E., Kulmala, J., Seitsamo, J., ... & Rantanen, T. (2014). Inverse Effects of Midlife Occupational and Leisure Time Physical Activity on Mobility Limitation in Old Age—A 28-Year Prospective Follow-Up Study. *Journal of the American Geriatrics Society*, *62*(5), 812-820.

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., . . . Adams Hillard, P. J. (2015). National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*, 1(1), 40-43.

Holmberg, A. H., Johnell, O., Nilsson, P. M., Nilsson, J., Berglund, G., & Åkesson, K. (2006). Risk factors for fragility fracture in middle age. A prospective population-based study of 33,000 men and women. *Osteoporosis international*, 17(7), 1065-1077.

Holtermann, A., Coenen, P., & Krause, N. (2020). The paradoxical health effects of occupational versus leisure-time physical activity. *Handbook of Socioeconomic Determinants of Occupational Health: From Macro-level to Micro-level Evidence*, 241-267.

Holtermann, A., Hansen, J. V., Burr, H., Søgaard, K., & Sjøgaard, G. (2012). The health paradox of occupational and leisure-time physical activity. *British journal of sports medicine*, *46*(4), 291-295.

Holtermann, A., Krause, N., Van Der Beek, A. J., & Straker, L. (2018). The physical activity paradox: six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does.

Horlings, C. G., Van Engelen, B. G., Allum, J. H., & Bloem, B. R. (2008). A weak balance: the contribution of muscle weakness to postural instability and falls. *Nature Clinical Practice Neurology*, 4(9), 504-515.

Hortobágyi, T., Finch, A., Solnik, S., Rider, P., & DeVita, P. (2011). Association between muscle activation and metabolic cost of walking in young and old adults. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 66(5), 541-547.

Houston, D. K., Nicklas, B. J., & Zizza, C. A. (2009). Weighty concerns: the growing prevalence of obesity among older adults. *Journal of the American Dietetic Association*, *109*(11), 1886–1895.

Howley, E. T. (2001). Type of activity: resistance, aerobic and leisure versus occupational physical activity. *Medicine and science in sports and exercise*, 33(6 Suppl), S364-9.

Hrubeniuk, T. J., Sénéchal, M., Mayo, A., & Bouchard, D. R. (2020). Association between physical function and various patterns of physical activity in older adults: a cross-sectional analysis. *Aging clinical and experimental research*, *32*(6), 1017-1024.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

Huang, Y., Li, L., Gan, Y., Wang, C., Jiang, H., Cao, S., & Lu, Z. (2020). Sedentary behaviors and risk of depression: a meta-analysis of prospective studies. Translational psychiatry, 10(1), 1-10.

Hughes, V. A., Frontera, W. R., Wood, M., Evans, W. J., Dallal, G. E., Roubenoff, R., & Singh, M. A. F. (2001). Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *56*(5), B209-B217.

Huiskes, R., Ruimerman, R., Van Lenthe, G. H., & Janssen, J. D. (2000). Effects of mechanical forces on maintenance and adaptation of form in trabecular bone. *Nature*, *405*(6787), 704-706.

Hulteen, R. M., Smith, J. J., Morgan, P. J., Barnett, L. M., Hallal, P. C., Colyvas, K., & Lubans, D. R. (2017). Global participation in sport and leisure-time physical activities: A systematic review and meta-analysis. *Preventive medicine*, *95*, 14-25.

Human Sciences Research Council. Media release no. 1: non-communicable diseases (NCDs). http://www.hsrc.ac.za/uploads/pageContent/3895/01%20NON-COMMUNICABLE%20DISEASES.pdf. Accessed February 2022.

Hyppönen, E., & Power, C. (2007). Hypovitaminosis D in British adults at age 45 y: nationwide cohort study of dietary and lifestyle predictors. The American journal of clinical nutrition, 85(3), 860-868.

Iezzoni, L. I., Davis, R. B., Soukup, J., & O'Day, B. (2003). Quality dimensions that most concern people with physical and sensory disabilities. *Archives of internal medicine*, 163(17), 2085-2092.

Incel, N. A., Ceceli, E., Durukan, P. B., Erdem, H. R., & Yorgancioglu, Z. R. (2002). Grip strength: effect of hand dominance. *Singapore medical journal*, *43*(5), 234-237.

International Society for Physical Activity and Health (ISPAH). ISPAH's Eight Investments That Work for Physical Activity. November 2020. Available from: www.ISPAH.org/Resources (accessed on May 5, 2021)

Ishigaki, E. Y., Ramos, L. G., Carvalho, E. S., & Lunardi, A. C. (2014). Effectiveness of muscle strengthening and description of protocols for preventing falls in the elderly: a systematic review. Brazilian journal of physical therapy, 18, 111-118.

Jain, R. K., & Vokes, T. (2019). Physical activity as measured by accelerometer in NHANES 2005–2006 is associated with better bone density and trabecular bone score in older adults. *Archives of osteoporosis*, 14(1), 1-7.

Janssen, I., Shepard, D. S., Katzmarzyk, P. T., & Roubenoff, R. (2004). The healthcare costs of sarcopenia in the United States. Journal of the American Geriatrics Society, 52(1), 80–85.

Janssen, I. (2006). Influence of sarcopenia on the development of physical disability: the Cardiovascular Health Study. *Journal of the American Geriatrics Society*, *54*(1), 56-62.

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*, 50(5), 889-896.

Jemmott III, J. B., Jemmott, L. S., Ngwane, Z., Zhang, J., Heeren, G. A., Icard, L. D., ... & Carty, C. (2014). Theory-based behavioral intervention increases self-reported physical activity in South African men: A cluster-randomized controlled trial. Preventive medicine, 64, 114-120.

Jin, L., & Hahn, M. E. (2019). Comparison of lower extremity joint mechanics between healthy active young and middle age people in walking and running gait. *Scientific reports*, 9(1), 1-8.

Jones, C. J., Rikli, R. E., & Beam, W. C. (1999). A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research quarterly for exercise and sport*, *70*(2), 113-119.

Jura, M., & Kozak, L. P. (2016). Obesity and related consequences to ageing. *Age (Dordrecht, Netherlands)*, 38(1), 23.

Kaji, H. (2014). Interaction between muscle and bone. Journal of bone metabolism, 21(1), 29-40.

Kalyani, R. R., Corriere, M., & Ferrucci, L. (2014). Age-related and disease-related muscle loss: the effect of diabetes, obesity, and other diseases. *The lancet Diabetes & endocrinology*, *2*(10), 819-829.

Kämpfen, F., Wijemunige, N., & Evangelista, B. (2018). Aging, non-communicable diseases, and old-age disability in low-and middle-income countries: a challenge for global health.

Kang, H. G., & Dingwell, J. B. (2009). Dynamics and stability of muscle activations during walking in healthy young and older adults. *Journal of biomechanics*, 42(14), 2231-2237.

Kankeu, H. T., Saksena, P., Xu, K., & Evans, D. B. (2013). The financial burden from non-communicable diseases in low-and middle-income countries: a literature review. *Health Research Policy and Systems*, 11(1), 1-12.

Karinkanta, S., Heinonen, A., Sievänen, H., Uusi-Rasi, K., Pasanen, M., Ojala, K., ... & Kannus, P. (2007). A multi-component exercise regimen to prevent functional decline and bone fragility in home-dwelling elderly women: randomized, controlled trial. Osteoporosis International, 18(4), 453-462.

Kay, D. B., Buysse, D. J., Germain, A., Hall, M., & Monk, T. H. (2015). Subjective–objective sleep discrepancy among older adults: associations with insomnia diagnosis and insomnia treatment. Journal of sleep research, 24(1), 32-39.Kawalkar, A. C. (2015). A comprehensive review on osteoporosis. *J Trauma*, *10*, 3-12.

Keller, K., & Engelhardt, M. (2013). Strength and muscle mass loss with aging process. Age and strength loss. *Muscles, ligaments and tendons journal*, *3*(4), 346.

Kepper, M. M., Myers, C. A., Denstel, K. D., Hunter, R. F., Guan, W., & Broyles, S. T. (2019). The neighborhood social environment and physical activity: a systematic scoping review. *International Journal of Behavioural Nutrition and Physical Activity*, 16(1), 1-14.

Kharb, A., Saini, V., Jain, Y. K., & Dhiman, S. (2011). A review of gait cycle and its parameters. IJCEM *International Journal of Computational Engineering & Management*, 13, 78-83.

Kikuchi, H., Inoue, S., Sugiyama, T., Owen, N., Oka, K., Nakaya, T., & Shimomitsu, T. (2014). Distinct associations of different sedentary behaviours with health-related attributes among older adults. *Preventive medicine*, *67*, 335–339.

Kim, C. H. (2016). Measurements of Adiposity and Body Composition. *The Korean Journal of Obesity*, 25(3), 115-120.

Kim, M., Yoshida, H., Sasai, H., Kojima, N., & Kim, H. (2015). Association between objectively measured sleep quality and physical function among community-dwelling oldest old Japanese: A cross-sectional study. *Geriatrics & gerontology international*, 15(8), 1040-1048.

Kim, S., Leng, X. I., & Kritchevsky, S. B. (2017). Body composition and physical function in older adults with various comorbidities. *Innovation in aging,* 1(1).

Kim, H., Suzuki, T., Saito, K., Yoshida, H., Kojima, N., Kim, M., ... & Tokimitsu, I. (2013). Effects of exercise and tea catechins on muscle mass, strength and walking ability in community-dwelling elderly Japanese sarcopenic women: a randomized controlled trial. Geriatrics & gerontology international, 13(2), 458-465.

Kim, Y., White, T., Wijndaele, K., Sharp, S. J., Wareham, N. J., & Brage, S. (2017). Adiposity and grip strength as long-term predictors of objectively measured physical activity in 93 015 adults: the UK Biobank study. *International Journal of Obesity*, 41(9), 1361-1368.

Knäuper, B., Carrière, K., Chamandy, M., Xu, Z., Schwarz, N., & Rosen, N. O. (2016). How aging affects self-reports. *European journal of ageing*, *13*(2), 185–193.

Kobayashi, D., Takahashi, O., Deshpande, G. A., Shimbo, T., & Fukui, T. (2012). Association between osteoporosis and sleep duration in healthy middle-aged and elderly adults: a large-scale, cross-sectional study in Japan. *Sleep and Breathing*, *16*(2), 579-583.

Koedijk, J. B., van Rijswijk, J., Oranje, W. A., van den Bergh, J. P., Bours, S. P., Savelberg, H. H., & Schaper, N. C. (2017). Sedentary behaviour and bone health in children, adolescents and young adults: a systematic review. *Osteoporosis International*, *28*(9), 2507-2519.

Kohrt, W. M., Bloomfield, S. A., Little, K. D., Nelson, M. E., & Yingling, V. R. (2004). Physical activity and bone health. *Medicine & Science in Sports & Exercise*, 36(11), 1985-1996.

Koster, A., & Schaap, L. A. (2015). The effect of type 2 diabetes on body composition of older adults. *Clinics in geriatric medicine*, *31*(1), 41-49.

Kovacs, C. R. (2005). Age-related changes in gait and obstacle avoidance capabilities in older adults: a review. *Journal of applied gerontology*, 24(1), 21-34.

Koyanagi, A., Stubbs, B., & Vancampfort, D. (2018). Correlates of sedentary behaviour in the general population: A cross-sectional study using nationally representative data from six low- and middle-income countries. *PloS one*, *13*(8), e0202222.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J., & Freedson, P. S. (2011). Validation of wearable monitors for assessing sedentary behaviour. *Medicine & Science in Sports & Exercise*, *43*(8), 1561-1567.

Kruger, H. S., Micklesfield, L. K., Wright, H. H., Havemann-Nel, L., & Goedecke, J. H. (2015). Ethnic-specific cut-points for sarcopenia: evidence from black South African women. *European journal of clinical nutrition*, *69*(7), 843-849.

Lambert, E. V., Kolbe-Alexander, T., Adlakha, D., Oyeyemi, A., Anokye, N. K., Goenka, S., ... & Salvo, D. (2020). Making the case for 'physical activity security': the 2020 WHO guidelines on physical activity and sedentary behaviour from a Global South perspective.

LaMonte, M. J., & Ainsworth, B. E. (2001). Quantifying energy expenditure and physical activity in the context of dose response. Medicine and science in sports and exercise, 33(6 Suppl), S370-8.

Lang, T., Streeper, T., Cawthon, P., Baldwin, K., Taaffe, D. R., & Harris, T. B. (2010). Sarcopenia: etiology, clinical consequences, intervention, and assessment. *Osteoporosis international*, *21*(4), 543-559.

Langsetmo, L., Hitchcock, C. L., Kingwell, E. J., Davison, K. S., Berger, C., Forsmo, S., ... & Research, T. C. M. O. S. (2012). Physical activity, body mass index and bone mineral density—associations in a prospective population-based cohort of women and men: The Canadian Multicentre Osteoporosis Study (CaMos). *Bone*, 50(1), 401-408.

LaRoche, D. P., Melanson, E. L., Baumgartner, M. P., Bozzuto, B. M., Libby, V. M., & Marshall, B. N. (2018). Physiological determinants of walking effort in older adults: should they be targets for physical activity intervention?. *GeroScience*, 40(3), 305-315.

Lauderdale, D. S., Chen, J. H., Kurina, L. M., Waite, L. J., & Thisted, R. A. (2016). Sleep duration and health among older adults: associations vary by how sleep is measured. *J Epidemiol Community Health*, 70(4), 361-366.

Lautenschlager, N. T., Almeida, O. P., Flicker, L., & Janca, A. (2004). Can physical activity improve the mental health of older adults?. *Annals of general hospital psychiatry*, 3(1), 1-5.

Leask, C. F., Harvey, J. A., Skelton, D. A., & Chastin, S. F. (2015). Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). *European Review of Aging and Physical Activity*, *12*(1), 1-8.

LeBouthillier, D. M., Thibodeau, M. A., & Asmundson, G. J. G. (2013). Severity of Fall-Based Injuries, Fear of Falling, and Activity Restriction: Sex Differences in a Population-Based Sample of Older Canadian Adults. *Journal of Aging and Health*, 25(8), 1378–1387.

Legrand, D., Vaes, B., Matheï, C., Adriaensen, W., Van Pottelbergh, G., & Degryse, J. M. (2014). Muscle strength and physical performance as predictors of mortality, hospitalization, and disability in the oldest old. *Journal of the American Geriatrics Society*, *62*(6), 1030-1038.

Leisman, G., Moustafa, A. A., & Shafir, T. (2016). Thinking, Walking, Talking: Integratory Motor and Cognitive Brain Function. *Frontiers in public health*, *4*, 94.

Leitzmann, M. F., Jochem, C., & Schmid, D. (Eds.). (2017). *Sedentary behaviour epidemiology*. Springer.

Leslie, W. D., Orwoll, E. S., Nielson, C. M., Morin, S. N., Majumdar, S. R., Johansson, H., ... & Kanis, J. A. (2014). Estimated lean mass and fat mass differentially affect femoral bone density and strength index but are not FRAX independent risk factors for fracture. *Journal of Bone and Mineral Research*, *29*(11), 2511-2519.

Li, G., Zhang, L., Wang, D., AIQudsy, L., Jiang, J. X., Xu, H., & Shang, P. (2019). Muscle-bone crosstalk and potential therapies for sarco-osteoporosis. *Journal of cellular biochemistry*, *120*(9), 14262-14273.

Li, J., & Gooneratne, N. S. (2019). Sleep and health in older adults. *In Sleep and health* (pp. 31-43). Academic Press.

Li, J., Vitiello, M. V., & Gooneratne, N. S. (2018). Sleep in Normal Aging. *Sleep medicine clinics*, 13(1), 1–11.

Li, K. Z., Abbud, G. A., Fraser, S. A., & DeMont, R. G. (2012). Successful adaptation of gait in healthy older adults during dual-task treadmill walking. *Aging, Neuropsychology, and Cognition*, 19(1-2), 150-167.

Li, W., Keegan, T. H., Sternfeld, B., Sidney, S., Quesenberry Jr, C. P., & Kelsey, J. L. (2006). Outdoor falls among middle-aged and older adults: a neglected public health problem. *American journal of public health*, 96(7), 1192-1200.

Li, X., Gong, X., & Jiang, W. (2017). Abdominal obesity and risk of hip fracture: a meta-analysis of prospective studies. *Osteoporosis International*, *28*(10), 2747-2757.

Liao, C. D., Tsauo, J. Y., Huang, S. W., Ku, J. W., Hsiao, D. J., & Liou, T. H. (2018). Effects of elastic band exercise on lean mass and physical capacity in older women with sarcopenic obesity: A randomized controlled trial. Scientific reports, 8(1), 1-13.

Lips, P. (2001). Vitamin D deficiency and secondary hyperparathyroidism in the elderly: consequences for bone loss and fractures and therapeutic implications. Endocrine reviews, 22(4), 477-501.

Looker, A. C., Borrud, L. G., Hughes, J. P., Fan, B., Shepherd, J. A., & Melton 3rd, L. J. (2012). Lumbar spine and proximal femur bone mineral density, bone mineral content, and bone area: United States, 2005-2008. *Vital and Health Statistics. Series 11*, Data from the National Health Survey, (251), 1-132.

Lord, S., Chastin, S. F. M., McInnes, L., Little, L., Briggs, P., & Rochester, L. (2011). Exploring patterns of daily physical and sedentary behaviour in community-dwelling older adults. *Age and ageing*, *40*(2), 205-210.

Lucassen, E. A., De Mutsert, R., Le Cessie, S., Appelman-Dijkstra, N. M., Rosendaal, F. R., Van Heemst, D., ... & NEO Study Group. (2017). Poor sleep quality and later sleep timing are risk factors for osteopenia and sarcopenia in middle-aged men and women: The NEO study. *PloS one*, *12*(5), e0176685.

Luo, M., Phongsavan, P., Bauman, A., Negin, J., Zhang, Z., & Ding, D. (2020). Correlates of Domain-Specific Physical Activity Among Older Adults in Six Low-to Middle-Income Countries: Analysis of Nationally Representative Samples From Study of Global Aging and Adult Health (SAGE)(Wave 1). *Journal of Aging and Physical Activity*, *1*(aop), 1-21.

Luo, Y., Jiang, K., & He, M. (2020). Association between grip strength and bone mineral density in general US population of NHANES 2013–2014. *Archives of osteoporosis*, 15(1), 1-9.

Lyons, E. J., Swartz, M. C., Lewis, Z. H., Martinez, E., & Jennings, K. (2017). Feasibility and acceptability of a wearable technology physical activity intervention with telephone counseling for mid-aged and older adults: a randomized controlled pilot trial. JMIR mHealth and uHealth, 5(3), e6967.

Mafuya, N., Peltzer, K., Chirinda, W., Musekiwa, A., Kose, Z., Hoosain, E., Davids, A., & Ramlagan, S. (2013). Self-reported prevalence of chronic non-communicable diseases and associated factors among older adults in South Africa. *Global health action*, 6, 20936.

Mainenti MRM, Rodrigues ÉDC, Oliveira JFD, Ferreira ADS, Dias CM, Silva ALDS (2011). Adiposity and postural balance control: correlations between bioelectrical impedance and stabilometric signals in elderly Brazilian women. *Clinics,* 66:1513–1518.

Maki, B. E. (1997). Gait changes in older adults: predictors of falls or indicators of fear?. *Journal of the American geriatrics society*, 45(3), 313-320.

Makino, K., Makizako, H., Doi, T., Tsutsumimoto, K., Hotta, R., Nakakubo, S., ... & Shimada, H. (2017). Fear of falling and gait parameters in older adults with and without fall history. *Geriatrics & gerontology international*, 17(12), 2455-2459.

Malenfant, J. H., & Batsis, J. A. (2019). Obesity in the geriatric population–a global health perspective. *Journal of Global Health Reports*, *3*.

Mañas, A., del Pozo-Cruz, B., García-García, F. J., Guadalupe-Grau, A., & Ara, I. (2017). Role of objectively measured sedentary behaviour in physical performance, frailty and mortality among older adults: A short systematic review. *European journal of sport science*, 17(7), 940-953.

Marcos-Pardo, P. J., González-Gálvez, N., López-Vivancos, A., Espeso-García, A., Martínez-Aranda, L. M., Gea-García, G. M., ... & Vaquero-Cristóbal, R. (2021). Sarcopenia, Diet, Physical Activity and Obesity in European Middle-Aged and Older Adults: The LifeAge Study. *Nutrients*, *13*(1), 8.

Marcus, R. L., Addison, O., Kidde, J. P., Dibble, L. E., & Lastayo, P. C. (2010). Skeletal muscle fat infiltration: impact of age, inactivity, and exercise. *The journal of nutrition, health & aging*, *14*(5), 362-366.

Marigold, D. S., & Patla, A. E. (2008). Age-related changes in gait for multi-surface terrain. *Gait & posture*, 27(4), 689-696.

Marzetti, E., Calvani, R., Tosato, M., Cesari, M., Di Bari, M., Cherubini, A., ... & Sprintt Consortium. (2017). Sarcopenia: an overview. *Aging clinical and experimental research*, *29*(1), 11-17.

Masgrau, A., Mishellany-Dutour, A., Murakami, H., Beaufrère, A. M., Walrand, S., Giraudet, C., ... & Boirie, Y. (2012). Time-course changes of muscle protein synthesis associated with obesity-induced lipotoxicity. *The Journal of physiology*, *590*(20), 5199-5210.

Mayhew, A. J., Amog, K., Phillips, S., Parise, G., McNicholas, P. D., De Souza, R. J., ... & Raina, P. (2019). The prevalence of sarcopenia in community-dwelling older adults, an exploration of differences between studies and within definitions: a systematic review and meta-analyses. Age and ageing, 48(1), 48-56.

Mayosi, B. M., Flisher, A. J., Lalloo, U. G., Sitas, F., Tollman, S. M., & Bradshaw, D. (2009). The burden of non-communicable diseases in South Africa. *The Lancet*, 374(9693), 934-947.

McGibbon, C. A. (2003). Toward a better understanding of gait changes with age and disablement: neuromuscular adaptation. *Exercise and sport sciences reviews,* 31(2), 102-108.

McGregor, D. E., Carson, V., Palarea-Albaladejo, J., Dall, P. M., Tremblay, M. S., & Chastin, S. F. (2018). Compositional analysis of the associations between 24-h movement behaviours and health indicators among adults and older adults from the Canadian health measure survey. *International journal of environmental research and public health*, *15*(8), 1779.

McGregor, D. E., Palarea-Albaladejo, J., Dall, P. M., del Pozo Cruz, B., & Chastin, S. F. (2019). Compositional analysis of the association between mortality and 24-hour movement behaviour from NHANES. *European journal of preventive cardiology*, 2047487319867783.

McGregor, D. E., Palarea-Albaladejo, J., Dall, P. M., Stamatakis, E., & Chastin, S. F. M. (2019). Differences in physical activity time-use composition associated with cardiometabolic risks. *Preventive medicine reports*, 13, 23-29.

McGregor, D.; Chastin, S.F.M.; Dall, P.; Palarea-Albaladejo, J. Physical Activity CoDa Regression Model (PACRM); OpenCoDa: Glasgow, UK, 2018.

McLean, J.; Dean, L.; Cheong, C.K.; Dougall, I.; Hinchcliffe, S.; Mirani, K.; Vosnaki, K.; Wilson, V. The Scottish Health Sur-vey , 2018 ed.; Main Report; 2018; Volume 1. Available online: https://www.gov.scot/publications/scottish-health-survey-2018-volume-1-main-report/ (accessed on Feb 7, 2021).

McMichan, L., Dick, M., Skelton, D. A., Chastin, S. F., Owen, N., Dunstan, D. W., ... & Mavroeidi, A. (2021). Sedentary behaviour and bone health in older adults: a systematic review. *Osteoporosis International*, 1-11.

Mekary, R. A., & Ding, E. L. (2019). Isotemporal Substitution as the Gold Standard Model for Physical Activity Epidemiology: Why It Is the Most Appropriate for Activity Time Research. *International journal of environmental research and public health*, 16(5), 797.

Menant, J. C., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2009). Effects of walking surfaces and footwear on temporo-spatial gait parameters in young and older people. *Gait & Posture*, 29(3), 392-397.

Mendham, A. E., Brooks, N. E., Micklesfield, L. K., Faber, M., Christensen, D. L., Gallagher, I. J., ... & Lambert, E. V. (2020). Sarcopenia in older black South African women and relationships with physical activity and protein intake. The Proceedings of the Nutrition Society, 79(OCE2).

Mendham, A. E., Goedecke, J. H., Micklesfield, L. K., Brooks, N. E., Faber, M., Christensen, D. L., ... & Hunter, A. M. (2021). Understanding factors associated with sarcopenic obesity in older African women from a low-income setting: a cross-sectional analysis. *BMC geriatrics*, *21*(1), 1-15.

Mesas, A. E., López-García, E., León-Muñoz, L. M., Guallar-Castillón, P., & Rodríguez-Artalejo, F. (2010). Sleep duration and mortality according to health status in older adults. *Journal of the American Geriatrics Society*, *58*(10), 1870-1877.

Mezick, E. J., Matthews, K. A., Hall, M., Strollo Jr, P. J., Buysse, D. J., Kamarck, T. W., ... & Reis, S. E. (2008). Influence of race and socioeconomic status on sleep: Pittsburgh Sleep SCORE project. *Psychosomatic medicine,* 70(4), 410.

Micklesfield, L. K., Lambert, E. V., Hume, D. J., Chantler, S., Pienaar, P. R., Dickie, K., Puoane, T., & Goedecke, J. H. (2013). Socio-cultural, environmental and behavioural determinants of obesity in black South African women. *Cardiovascular journal of Africa*, *24*(9-10), 369–375.

Micklesfield, L., Rosenberg, L., Cooper, D., Hoffman, M., Kalla, A., Stander, I., & Lambert, E. (2003). Bone mineral density and lifetime physical activity in South African women. *Calcified tissue international*, *73*(5), 463-469.

Milanović, Z., Pantelić, S., Trajković, N., Sporiš, G., Kostić, R., & James, N. (2013). Age-related decrease in physical activity and functional fitness among elderly men and women. Clinical interventions in aging, 8, 549–556.

Minkel, J., Moreta, M., Muto, J., Htaik, O., Jones, C., Basner, M., & Dinges, D. (2014). Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. Health Psychology, 33(11), 1430.

Mitchell, W. K., Atherton, P. J., Williams, J., Larvin, M., Lund, J. N., & Narici, M. (2012). Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Frontiers in physiology*, *3*, 260.

Mlangeni, L., Makola, L., Naidoo, I., Chibi, B., Sokhela, Z., Silimfe, Z., & Mabaso, M. (2018). Factors associated with physical activity in South Africa: evidence from a National Population Based Survey. *The Open Public Health Journal*, *11*(1).

Moolla, R., Kotze, N., & Block, L. (2011). Housing satisfaction and quality of life in RDP houses in Braamfischerville, Soweto: A South African case study. *Urbani izziv*, 22(1), 138-143.
Mobily, K. E. (2014). Walking among older adults. World Leisure Journal, 56(2), 130-140.

Momma, H., Kawakami, R., Honda, T., & Sawada, S. S. (2022). Muscle-strengthening activities are associated with lower risk and mortality in major non-communicable diseases: a systematic review and meta-analysis of cohort studies. British Journal of Sports Medicine, bjsports-2021-105061.

Mora, S., & Gilsanz, V. (2003). Establishment of peak bone mass. *Endocrinology and Metabolism Clinics*, *32*(1), 39-63.

Morgan, P. T., Smeuninx, B., & Breen, L. (2020). Exploring the Impact of Obesity on Skeletal Muscle Function in Older Age. *Frontiers in Nutrition*, 7, 286.

Mudie, K., Jin, M. M., Tan, L. K., Addo, J., dos-Santos-Silva, I., Quint, J., ... & Perel, P. (2019). Non-communicable diseases in sub-Saharan Africa: a scoping review of large cohort studies. *Journal of global health*, *9*(2).

Muir, B. C., Haddad, J. M., van Emmerik, R. E. A., & Rietdyk, S. (2019). Changes in the control of obstacle crossing in middle age become evident as gait task difficulty increases. *Gait & posture*, 70, 254-259.

Mulligan, A. A., Luben, R. N., Bhaniani, A., Parry-Smith, D. J., O'Connor, L., Khawaja, A. P., ... & Khaw, K. T. (2014). EPIC-Norfolk FFQ Study. A new tool for converting food frequency questionnaire data into nutrient and food group values: FETA research methods and availability. *BMJ Open*, 4, e004503.

Mullington, J. M., Haack, M., Toth, M., Serrador, J. M., & Meier-Ewert, H. K. (2009). Cardiovascular, inflammatory, and metabolic consequences of sleep deprivation. *Progress in cardiovascular diseases*, *51*(4), 294-302.

Muñoz-Garach, A., García-Fontana, B., & Muñoz-Torres, M. (2020). Nutrients and dietary patterns related to osteoporosis. Nutrients, 12(7), 1986.

Murray, N. M. F. (1995). Anatomical Guide for the Electromyographer. *Journal of Anatomy*, 186(Pt 2), 449.

Nakakubo, S., Makizako, H., Doi, T., Tsutsumimoto, K., Hotta, R., Lee, S., ... & Shimada, H. (2018). Long and short sleep duration and physical frailty in community-dwelling older adults. *The journal of nutrition, health & aging*, 22(9), 1066-1071.

Nebes, R. D., Buysse, D. J., Halligan, E. M., Houck, P. R., & Monk, T. H. (2009). Self-reported sleep quality predicts poor cognitive performance in healthy older adults. *The Journals of Gerontology: Series B*, 64(2), 180-187.

Ng, C. A., Scott, D., Seibel, M. J., Cumming, R. G., Naganathan, V., Blyth, F. M., ... & Hirani, V. (2021). Higher-Impact Physical Activity Is Associated With Maintenance of Bone Mineral Density But Not Reduced Incident Falls or Fractures in Older Men: The Concord Health and Aging in Men Project. *Journal of bone and mineral research*, 36(4), 662-672.

Nielsen, B. R., Abdulla, J., Andersen, H. E., Schwarz, P., & Suetta, C. (2018). Sarcopenia and osteoporosis in older people: a systematic review and meta-analysis. *European Geriatric Medicine*, 9(4), 419-434.

Nuttall F. Q. (2015). Body Mass Index: Obesity, BMI, and Health: A Critical Review. *Nutrition today*, *50*(3), 117–128.

O'donoghue, G., Perchoux, C., Mensah, K., Lakerveld, J., Van Der Ploeg, H., Bernaards, C., ... & Nazare, J. A. (2016). A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. *BMC public health*, *16*(1), 1-25.

Odunitan-Wayas, F. A., Faber, M., Mendham, A. E., Goedecke, J. H., Micklesfield, L. K., Brooks, N. E., ... & Lambert, E. V. (2021). Food Security, Dietary Intake and Foodways of Urban Low-Income Older South African Women: An Exploratory Study. *International journal of environmental research and public health*, *18*(8), 3973.

Oikawa, S. Y., Holloway, T. M., & Phillips, S. M. (2019). The impact of step reduction on muscle health in aging: protein and exercise as countermeasures. *Frontiers in nutrition*, *6*, 75.

Onambele-Pearson, G., Wullems, J., Doody, C., Ryan, D., Morse, C., & Degens, H. (2019). Influence of Habitual Physical Behaviour–Sleeping, Sedentarism, Physical Activity–On Bone Health in Community-Dwelling Older People. *Frontiers in physiology*, 10, 408.Ory, M. G., Towne, S. D., Won, J., Forjuoh, S. N., & Lee, C. (2016). Social and environmental predictors of walking among older adults. BMC geriatrics, 16(1), 1-13.

Owen, N., Sugiyama, T., Eakin, E. E., Gardiner, P. A., Tremblay, M. S., & Sallis, J. F. (2011). Adults' sedentary behaviour: determinants and interventions. *American journal of preventive medicine*, 41(2), 189-196.

Oyeyemi, A. L., Adegoke, B. O., Oyeyemi, A. Y., Deforche, B., Bourdeaudhuij, I. D., & Sallis, J. F. (2012). Environmental factors associated with overweight among adults in Nigeria. International Journal of Behavioral Nutrition and Physical Activity, 9(1), 1-9.

Oyeyemi, A. L., Kolo, S. M., Rufai, A. A., Oyeyemi, A. Y., Omotara, B. A., & Sallis, J. F. (2019). Associations of neighborhood walkability with sedentary time in Nigerian older adults. *International journal of environmental research and public health*, *16*(11), 1879.

Palma, A., & Assis, M. (2011). Rich and physically active: where are we talking from?. *Scandinavian journal of medicine & science in sports*, 21(1), 151-2.

Palmer, V. J., Gray, C. M., Fitzsimons, C. F., Mutrie, N., Wyke, S., Deary, I. J., ... & Skelton, D. A. (2019). What do older people do when sitting and why? Implications for decreasing sedentary behaviour. *The Gerontologist*, 59(4), 686-697.

Palombaro, K. M., Black, J. D., Buchbinder, R., & Jette, D. U. (2013). Effectiveness of exercise for managing osteoporosis in women postmenopause. *Physical therapy*, *93*(8), 1021-1025.

Pampel, F. C., Krueger, P. M., & Denney, J. T. (2010). Socioeconomic disparities in health behaviours. *Annual review of sociology*, 36, 349-370.

Parr, E. B., Coffey, V. G., & Hawley, J. A. (2013). 'Sarcobesity': a metabolic conundrum. *Maturitas*, *74*(2), 109–113.

Patel, H. P., Dawson, A., Westbury, L. D., Hasnaoui, G., Syddall, H. E., Shaw, S., ... & Dennison, E. M. (2018). Muscle mass, muscle morphology and bone health among community-dwelling older men: Findings from the Hertfordshire Sarcopenia Study (HSS). *Calcified tissue international*, 103(1), 35-43.

Patterson, R., McNamara, E., Tainio, M., de Sá, T. H., Smith, A. D., Sharp, S. J., ... & Wijndaele, K. (2018). Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *European journal of epidemiology*, *33*(9), 811-829.

Pau, M., Leban, B., Collu, G., & Migliaccio, G. M. (2014). Effect of light and vigorous physical activity on balance and gait of older adults. *Archives of gerontology and geriatrics*, *59*(3), 568-573.

Peberdy, S., & Majodina, Z. (2000, June). ‘Just a roof over my head’?. In *Urban Forum* (Vol. 11, No. 2, pp. 273-288). Springer Netherlands.

Peeters, A., & Backholer, K. (2012). Is the health burden associated with obesity changing?. *American journal of epidemiology*, *176*(10), 840-845.

Pelclová, J., Štefelová, N., Hodonská, J., Dygrýn, J., Gába, A., & Zając-Gawlak, I. (2018). Reallocating time from sedentary behaviour to light and moderate-to-vigorous physical activity: what has a stronger association with adiposity in older adult women?. *International journal of environmental research and public health*, *15*(7), 1444.

Peltzer, K. (2012). Sociodemographic and health correlates of sleep problems and duration in older adults in South Africa. *South African Journal of Psychiatry*, 18(4), 150-156.

Peltzer, K. (2017). Differences in sleep duration among four different population groups of older adults in South Africa. *International journal of environmental research and public health*, *14*(5), 502.

Peltzer, K., & Pengpid, S. (2017). Sleep duration, sleep quality, body mass index, and waist circumference among young adults from 24 low-and middle-income and two high-income countries. *International journal of environmental research and public health*, *14*(6), 566.

Peltzer, K., & Phaswana-Mafuya, N. (2012). Physical inactivity and associated factors in older adults in South Africa: geriatrics. *African Journal for Physical Health Education, Recreation and Dance*, *18*(3), 447-460.

Perry, J., & Burnfield, J. M. (1993). Gait analysis: normal and pathological function. *Developmental Medicine and Child Neurology*, 35, 1122-1122.

Pescatello, L. S., Franklin, B. A., Fagard, R., Farquhar, W. B., Kelley, G. A., Ray, C. A., & American College of Sports Medicine (2004). American College of Sports Medicine position stand. Exercise and hypertension. *Medicine and science in sports and exercise*, *36*(3), 533–553.

Phaswana-Mafuya, N., Peltzer, K., & Pengpid, S. (2018). Prevalence and correlates of sedentary behaviour among a national sample of 15-98 years old individuals in South Africa. *African Journal for Physical Activity and Health Sciences (AJPHES)*, *24*(3), 286-298.

Phillips, E. A., Comeau, D. L., Pisa, P. T., Stein, A. D., & Norris, S. A. (2016). Perceptions of diet, physical activity, and obesity-related health among black daughter-mother pairs in Soweto, South Africa: a qualitative study. BMC Public Health, 16(1), 1-10.

Piasecki, M., Ireland, A., Jones, D. A., & McPhee, J. S. (2016). Age-dependent motor unit remodelling in human limb muscles. *Biogerontology*, 17(3), 485-496.

Piasecki, M., Ireland, A., Piasecki, J., Stashuk, D. W., Swiecicka, A., Rutter, M. K., ... & McPhee, J. S. (2018). Failure to expand the motor unit size to compensate for declining motor unit numbers distinguishes sarcopenic from non-sarcopenic older men. *The Journal of physiology*, 596(9), 1627-1637.

Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *Journal of Epidemiology & Community Health*, 55(2), 111-122.

Piggin, J. (2020). What is physical activity? A holistic definition for teachers, researchers and policy makers. Frontiers in sports and active living, 2, 72.

Pijnappels, M., Reeves, N. D., & van Dieën, J. H. (2008). Identification of elderly fallers by muscle strength measures. *European journal of applied physiology*, 102(5), 585-592.

Pinedo-Villanueva, R., Westbury, L. D., Syddall, H. E., Sanchez-Santos, M. T., Dennison, E. M., Robinson, S. M., & Cooper, C. (2019). Health care costs associated with muscle weakness: a UK population-based estimate. *Calcified tissue international*, *104*(2), 137-144.

Pinheiro, M. B., Oliveira, J., Bauman, A., Fairhall, N., Kwok, W., & Sherrington, C. (2020). Evidence on physical activity and osteoporosis prevention for people aged 65+ years: a systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. *International Journal of Behavioural Nutrition and Physical Activity*, 17(1), 1-53.

Piovezan, R. D., Abucham, J., Dos Santos, R. V. T., Mello, M. T., Tufik, S., & Poyares, D. (2015). The impact of sleep on age-related sarcopenia: Possible connections and clinical implications. Ageing research reviews, 23, 210-220.

Pirkle, C., Peltzer, N., Câmara, S., Gomes, J., & Ylli, A. (2020). Burden of food insecurity in older adults from diverse global settings: policy recommendations. *European Journal of Public Health*, *30*(Supplement_5), ckaa166-311.

Pi-Sunyer, X. (2019). Changes in body composition and metabolic disease risk. *European journal of clinical nutritio*n, 73(2), 231-235.

Podsiadlo, D., & Richardson, S. (1991). The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. *Journal of the American geriatrics Society*, 39(2), 142-148.

Pourmotabbed, A., Ghaedi, E., Babaei, A., Mohammadi, H., Khazaie, H., Jalili, C., ... & Miraghajani, M. (2019). Sleep duration and sarcopenia risk: a systematic review and dose-response meta-analysis. *Sleep and Breathing*, 1-12.

Powell, C., Browne, L. D., Carson, B. P., Dowd, K. P., Perry, I. J., Kearney, P. M., ... & Donnelly, A. E. (2020). Use of compositional data analysis to show estimated changes in cardiometabolic health by reallocating time to light-intensity physical activity in older adults. *Sports Medicine*, 50(1), 205-217.

Pretorius, S., Stewart, S., Carrington, M. J., Lamont, K., Sliwa, K., & Crowther, N. J. (2015). Is there an association between sleeping patterns and other environmental factors with obesity and blood pressure in an urban African population?. *PLoS One*, 10(10), e0131081.

Puoane, T., & Mciza, Z. (2009). Socio-cultural and environmental factors related to obesity in black Africans: A perspective from South Africa. Obesity: a multidimensional approach to contemporary global issue. New Delhi: Dhanraj Book House, 91-98.

Puoane, T., Steyn, K., Bradshaw, D., Laubscher, R., Fourie, J., Lambert, V. and Mbananga, N. (2002), Obesity in South Africa: The South African Demographic and Health Survey. *Obesity Research*, 10: 1038-1048.

Qu, X., Zhang, X., Zhai, Z., Li, H., Liu, X., Li, H., Liu, G., Zhu, Z., Hao, Y., & Dai, K. (2014). Association between physical activity and risk of fracture. *Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research*, 29(1), 202–211.

Rae, D. E., Pienaar, P. R., Henst, R. H., Roden, L. C., & Goedecke, J. H. (2018). Associations between long self-reported sleep, obesity and insulin resistance in a cohort of premenopausal Black and White South African women. *Sleep Health*, 4(6), 558-564.

Ramanathan, A. K., Kiran, P., Arnold, G. P., Wang, W., & Abboud, R. J. (2010). Repeatability of the Pedar-X® in-shoe pressure measuring system*. Foot and ankle surgery*, 16(2), 70-73.

Rantanen, T. (2013). Promoting mobility in older people. *Journal of Preventive Medicine and Public Health*, 46(Suppl 1), S50.

Raut, M. K. (2019). Global age-specific denominator estimation for monitoring of health and nutrition SDGs and indicators based on population projections of the UN World population prospects, 2017 revision, for the year 2018. *International Journal of Community Medicine and Public Health*, 6(1), 177.

Reid, N., Healy, G. N., Gianoudis, J., Formica, M., Gardiner, P. A., Eakin, E. E., ... & Daly, R. M. (2018). Association of sitting time and breaks in sitting with muscle mass, strength, function, and inflammation in community-dwelling older adults. *Osteoporosis International*, *29*(6), 1341-1350.

Reuter, C., Bellettiere, J., Liles, S., Di, C., Sears, D. D., LaMonte, M. J., ... & Natarajan, L. (2020). Diurnal patterns of sedentary behaviour and changes in physical function over time among older women: a prospective cohort study. *International Journal of Behavioural Nutrition and Physical Activity,* 17(1), 1-11.

Riebe, D., Garber, C. E., Rossi, J. S., Greaney, M. L., Nigg, C. R., Lees, F. D., ... & Clark, P. G. (2005). Physical activity, physical function, and stages of change in older adults. *American journal of health behaviour*, *29*(1), 70-80.

Riva, F., Bisi, M. C., & Stagni, R. (2014). Gait variability and stability measures: Minimum number of strides and within-session reliability. *Computers in biology and medicine*, 50, 9-13.

Roberts, C. E., Phillips, L. H., Cooper, C. L., Gray, S., & Allan, J. L. (2017). Effect of different types of physical activity on activities of daily living in older adults: systematic review and meta-analysis. *Journal of Aging and Physical Activity*, 25(4), 653-670.

Roberts, L. M., Jaeger, B. C., Baptista, L. C., Harper, S. A., Gardner, A. K., Jackson, E. A., ... & Buford, T. W. (2019). Wearable technology to reduce sedentary behavior and CVD risk in older adults: a pilot randomized clinical trial. Clinical interventions in aging, 14, 1817.

Rodriguez-Gomez, I., Manas, A., Losa-Reyna, J., Rodriguez-Manas, L., Chastin, S. F. M., Alegre, L. M., . . . Ara, I. (2018). Associations between sedentary time, physical activity and bone health among older people using compositional data analysis. *PLoS One*, 13(10), e0206013.

Rodriguez-Gomez, I., Manas, A., Losa-Reyna, J., Rodriguez-Manas, L., Chastin, S. F. M., Alegre, L. M., . . . Ara, I. (2019). The Impact of Movement Behaviours on Bone Health in Elderly with Adequate Nutritional Status: Compositional Data Analysis Depending on the Frailty Status. *Nutrients*, 11(3).

Rodríguez-Gómez, I., Mañas, A., Losa-Reyna, J., Rodríguez-Mañas, L., Chastin, S. F., Alegre, L. M., ... & Ara, I. (2020). Prospective changes in the distribution of movement behaviours are associated with bone health in the elderly according to variations in their frailty levels. *Journal of Bone and Mineral Research*, 35(7), 1236-1245.

Rollo, S., Antsygina, O., & Tremblay, M. S. (2020). The whole day matters: understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. *Journal of sport and health science*, 9(6), 493-510.

Rom, O., Kaisari, S., Aizenbud, D., & Reznick, A. Z. (2012). Lifestyle and sarcopenia—etiology, prevention, and treatment. *Rambam Maimonides Medical Journal*, *3*(4).

Rosenberg, D. E., Anderson, M. L., Renz, A., Matson, T. E., Lee, A. K., Greenwood-Hickman, M. A., ... & McClure, J. B. (2020). Reducing sitting time in obese older adults: the I-STAND randomized controlled trial. Journal of aging and physical activity, 28(6), 864-874.

Rosengren, K. S., McAuley, E., & Mihalko, S. L. (1998). Gait adjustments in older adults: activity and efficacy influences. *Psychology and aging*, 13(3), 375.

Ross, R., Chaput, J. P., Giangregorio, L. M., Janssen, I., Saunders, T. J., Kho, M. E., ... & Tremblay, M. S. (2020). Canadian 24-Hour Movement Guidelines for Adults aged 18–64 years and Adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and sleep. *Applied Physiology, Nutrition, and Metabolism*, *45*(10), S57-S102.

Roubenoff, R. (2000). Sarcopenia and its implications for the elderly. *European journal of clinical nutrition*, *54*(3), S40-S47.

Rubio-Arias, J. Á., Rodríguez-Fernández, R., Andreu, L., Martínez-Aranda, L. M., Martínez-Rodriguez, A., & Ramos-Campo, D. J. (2019). Effect of sleep quality on the prevalence of sarcopenia in older adults: A systematic review with meta-analysis. *Journal of clinical medicine*, *8*(12), 2156.

SAFOODS. SAMRC Food Composition Tables for South Africa. Cape Town: South African Medical Research Council; 5th Edition. 2017.

SAFOODS. SAMRC Food Quantities Manual for South Africa. Cape Town: South African Medical Research Council; 3rd Edition. 2018.

Salman, A., & Sellami, M. (2019). Do older adults with multimorbidity meet the recommended levels of physical activity? An analysis of Scottish Health Survey*. International journal of environmental research and public health*, 16(19), 3748.

Salzman, B. (2010). Gait and balance disorders in older adults. *American family physician*, 82(1), 61-68.

Sánchez-Sánchez, J. L., Mañas, A., García-García, F. J., Ara, I., Carnicero, J. A., Walter, S., & Rodríguez-Mañas, L. (2019). Sedentary behaviour, physical activity, and sarcopenia among older adults in the TSHA: isotemporal substitution model. *Journal of cachexia, sarcopenia and muscle*, *10*(1), 188-198.

Santos, D. A., Silva, A. M., Baptista, F., Santos, R., Vale, S., Mota, J., & Sardinha, L. B. (2012). Sedentary behaviour and physical activity are independently related to functional fitness in older adults. *Experimental gerontology*, *47*(12), 908-912.

Santos-Lozano, A., Santin-Medeiros, F., Cardon, G., Torres-Luque, G., Bailon, R., Bergmeir, C., ... & Garatachea, N. (2013). Actigraph GT3X: validation and determination of physical activity intensity cut points. *International journal of sports medicine*, *34*(11), 975-982.

Sardinha, L. B., Santos, D. A., Silva, A. M., Baptista, F., & Owen, N. (2015). Breaking-up sedentary time is associated with physical function in older adults. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 70(1), 119-124.

Sasaki, N., Fujiwara, S., Yamashita, H., Ozono, R., Teramen, K., & Kihara, Y. (2016). Impact of sleep on osteoporosis: sleep quality is associated with bone stiffness index. *Sleep medicine*, *25*, 73-77.

Sattler, M. C., Ainsworth, B. E., Andersen, L. B., Foster, C., Hagströmer, M., Jaunig, J., ... & van Poppel, M. N. (2021). Physical activity self-reports: past or future?.

Schafer, M. J., Atkinson, E. J., Vanderboom, P. M., Kotajarvi, B., White, T. A., Moore, M. M., ... & LeBrasseur, N. K. (2016). Quantification of GDF11 and myostatin in human aging and cardiovascular disease. Cell metabolism, 23(6), 1207-1215.

Schloemer, S. A., Thompson, J. A., Silder, A., Thelen, D. G., & Siston, R. A. (2017). Age-related differences in gait kinematics, kinetics, and muscle function: a principal component analysis. *Annals of biomedical engineering*, 45(3), 695-710.

Schmitz, A., Silder, A., Heiderscheit, B., Mahoney, J., & Thelen, D. G. (2009). Differences in lower-extremity muscular activation during walking between healthy older and young adults. *Journal of electromyography and kinesiology*, 19(6), 1085-1091.Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2016). Effects of resistance training frequency on measures of muscle hypertrophy: a systematic review and meta-analysis. Sports medicine, 46(11), 1689-1697.

Scholes, S., & Mindell, J. S. (2020). Inequalities in participation and time spent in moderate-to-vigorous physical activity: a pooled analysis of the cross-sectional health surveys for England 2008, 2012, and 2016. *BMC public health*, *20*(1), 1-12.

Schutte, A. E., Srinivasapura Venkateshmurthy, N., Mohan, S., & Prabhakaran, D. (2021). Hypertension in low-and middle-income countries. *Circulation research*, *128*(7), 808-826.

Scott, D., Johansson, J., Gandham, A., Ebeling, P. R., Nordstrom, P., & Nordstrom, A. (2020). Associations of accelerometer-determined physical activity and sedentary behaviour with sarcopenia and incident falls over 12 months in community-dwelling Swedish older adults. *Journal of Sport and Health Science*.

Scott, D., Shore-Lorenti, C., McMillan, L. B., Mesinovic, J., Clark, R. A., Hayes, A., ... & Ebeling, P. R. (2018). Calf muscle density is independently associated with physical function in overweight and obese older adults. *Journal of musculoskeletal & neuronal interactions*, *18*(1), 9.

Scottish Health Survey 2019—Volume 1: Main Report—gov.scot. Available online: https://www.gov.scot/publications/scottish-health-survey-2019-volume-1-main-report/pages/10/ (accessed on March 10, 2021).

Seedat, Y. K., & Rayner, B. L. (2014). The abridged South African hypertension guideline 2011. *South African Family Practice, 54*(2), S4-S8.

Sellers, C., Dall, P., Grant, M., & Stansfield, B. (2016). Agreement of the activPAL3 and activPAL for characterising posture and stepping in adults and children. *Gait & posture*, *48*, 209-214.

Senior, H. E., Henwood, T. R., Beller, E. M., Mitchell, G. K., & Keogh, J. W. (2015). Prevalence and risk factors of sarcopenia among adults living in nursing homes. *Maturitas*, *82*(4), 418-423.

Shad, B. J., Wallis, G., Van Loon, L. J., & Thompson, J. L. (2016). Exercise prescription for the older population: The interactions between physical activity, sedentary time, and adequate nutrition in maintaining musculoskeletal health. *Maturitas*, 93, 78-82.Sharir, A., Stern, T., Rot, C., Shahar, R., & Zelzer, E. (2011). Muscle force regulates bone shaping for optimal load-bearing capacity during embryogenesis. Development, 138(15), 3247-3259.

Shankar, A., McMunn, A., Demakakos, P., Hamer, M., & Steptoe, A. (2017). Social isolation and loneliness: Prospective associations with functional status in older adults. *Health psychology*, 36(2), 179.

Shavers, V. L. (2007). Measurement of socioeconomic status in health disparities research. *Journal of the national medical association*, 99(9), 1013.

Shisana, O., Labadarios, D., Rehle, T., Simbayi, L., Zuma, K., Dhansay, A., ... & Faber, M. (2014). The South African National Health and Nutrition Examination Survey, 2012: SANHANES-1: the health and nutritional status of the nation.

Shuhart, C. R., Yeap, S. S., Anderson, P. A., Jankowski, L. G., Lewiecki, E. M., Morse, L. R., ... & Shepherd, J. A. (2019). Executive summary of the 2019 ISCD position development conference on monitoring treatment, DXA cross-calibration and least significant change, spinal cord injury, peri-prosthetic and orthopedic bone health, transgender medicine, and pediatrics. *Journal of Clinical Densitometry*, 22(4), 453-471.

Sinclair, A. J., & Abdelhafiz, A. H. (2020). Cardiometabolic disease in the older person: prediction and prevention for the generalist physician. *Cardiovascular endocrinology & metabolism*, *9*(3), 90–95.

Smit, W., de Lannoy, A., Dover, R. V., Lambert, E. V., Levitt, N., & Watson, V. (2016). Making unhealthy places: The built environment and non-communicable diseases in Khayelitsha, Cape Town. *Health & place*, 39, 196-203.

Smith, E. L., & Raab, D. M. (1986). Osteoporosis and physical activity. *Acta Medica Scandinavica*, *220*(S711), 149-156.

Smith, I., Salazar, I., RoyChoudhury, A., & St-Onge, M. P. (2019). Sleep restriction and testosterone concentrations in young healthy males: randomized controlled studies of acute and chronic short sleep. Sleep health, 5(6), 580-586.

Song, C., Wang, J., Kim, B., Lu, C., Zhang, Z., Liu, H., ... & Li, F. (2018). Insights into the role of circadian rhythms in bone metabolism: a promising intervention target?. *BioMed research international*, *2018*.

Sousa-Santos, A. R., & Amaral, T. F. (2017). Differences in handgrip strength protocols to identify sarcopenia and frailty-a systematic review. *BMC geriatrics,* 17(1), 1-21.

Sperry, S. D., Scully, I. D., Gramzow, R. H., & Jorgensen, R. S. (2015). Sleep duration and waist circumference in adults: a meta-analysis. *Sleep*, *38*(8), 1269-1276.

Spiegel, K., Tasali, E., Leproult, R., & Van Cauter, E. (2009). Effects of poor and short sleep on glucose metabolism and obesity risk. *Nature Reviews Endocrinology*, *5*(5), 253.

Spira, A. P., Covinsky, K., Rebok, G. W., Punjabi, N. M., Stone, K. L., Hillier, T. A., ... & Yaffe, K. (2012). Poor sleep quality and functional decline in older women. *Journal of the American Geriatrics Society*, 60(6), 1092-1098.

Stalsberg, R., & Pedersen, A. V. (2018). Are differences in physical activity across socioeconomic groups associated with choice of physical activity variables to report*?. International journal of environmental research and public health*, 15(5), 922.

Stamatakis, E., Coombs, N., Rowlands, A., Shelton, N., & Hillsdon, M. (2014). Objectively-assessed and self-reported sedentary time in relation to multiple socioeconomic status indicators among adults in England: a cross-sectional study. BMJ *open*, 4(11).

Stamatakis, E., Grunseit, A. C., Coombs, N., Ding, D., Chau, J. Y., Phongsavan, P., & Bauman, A. (2014). Associations between socio-economic position and sedentary behaviour in a large population sample of Australian middle and older-aged adults: The Social, Economic, and Environmental Factor (SEEF) Study. *Preventive medicine*, *63*, 72-80.

Steeves, J. A., Shiroma, E. J., Conger, S. A., Van Domelen, D., & Harris, T. B. (2019). Physical activity patterns and multimorbidity burden of older adults with different levels of functional status: NHANES 2003–2006. *Disability and health journal*, 12(3), 495-502.

Steffl, M., Bohannon, R. W., Sontakova, L., Tufano, J. J., Shiells, K., & Holmerova, I. (2017). Relationship between sarcopenia and physical activity in older people: a systematic review and meta-analysis. *Clinical interventions in aging*, 12, 835.

Stegeman, D., & Hermens, H. (2007). Standards for surface electromyography: The European project Surface EMG for non-invasive assessment of muscles (SENIAM). *Enschede: Roessingh Research and Development*, 108-12.

Stenholm, S., Alley, D., Bandinelli, S., Griswold, M. E., Koskinen, S., Rantanen, T., ... & Ferrucci, L. (2009). The effect of obesity combined with low muscle strength on decline in mobility in older persons: results from the InCHIANTI study. *International journal of obesity*, 33(6), 635-644.

Stenholm, S., Koster, A., Valkeinen, H., Patel, K. V., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2016). Association of physical activity history with physical function and mortality in old age. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *71*(4), 496-501.

Stenholm, S., Kronholm, E., Sainio, P., Borodulin, K., Era, P., Fogelholm, M., ... & Koskinen, S. (2010). Sleep-related factors and mobility in older men and women. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *65*(6), 649-657.

Straight, C. R., Toth, M. J., & Miller, M. S. (2021). Current perspectives on obesity and skeletal muscle contractile function in older adults. *Journal of Applied Physiology*, *130*(1), 10-16.

Strain, T., Fitzsimons, C., 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.

Strain, T., Kelly, P., Mutrie, N., & Fitzsimons, C. (2018). Differences by age and sex in the sedentary time of adults in Scotland. *Journal of sports sciences*, 36(7), 732-741.

Strain, T., Fitzsimons, C., 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.

Strain, T., Wijndaele, K., Garcia, L., Cowan, M., Guthold, R., Brage, S., & Bull, F. C. (2020). Levels of domain-specific physical activity at work, in the household, for travel and for leisure among 327 789 adults from 104 countries. *British journal of sports medicine*, 54(24), 1488-1497.

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., ... & Swartz, A. M. (2013). Guide to the assessment of physical activity: clinical and research applications: a scientific statement from the American Heart Association. *Circulation*, 128(20), 2259-2279.

Stubbs, B., Vancampfort, D., Veronese, N., Schofield, P., Lin, P. Y., Tseng, P. T., ... & Koyanagi, A. (2018). Multimorbidity and perceived stress: a population-based cross-sectional study among older adults across six low-and middle-income countries. *Maturitas*, 107, 84-91.

Studenski, S. A., Peters, K. W., Alley, D. E., Cawthon, P. M., McLean, R. R., Harris, T. B., ... & Vassileva, M. T. (2014). The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 69(5), 547-558.

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., ... & Guralnik, J. (2011). Gait speed and survival in older adults. *Jama*, 305(1), 50-58.

Sumukadas, D., Witham, M., Struthers, A., & McMurdo, M. (2009). Day length and weather conditions profoundly affect physical activity levels in older functionally impaired people. Journal of Epidemiology & Community Health, 63(4), 305-309.

Sun, F., Norman, I. J., & While, A. E. (2013). Physical activity in older people: a systematic review. *BMC public health*, *13*, 449.

Szanton, S. L., Walker, R. K., Roberts, L., Thorpe Jr, R. J., Wolff, J., Agree, E., ... & Seplaki, C. (2015). Older adults' favorite activities are resoundingly active: findings from the NHATS study. *Geriatric Nursing*, 36(2), 131-135.

Takayanagi, N., Sudo, M., Yamashiro, Y., Lee, S., Kobayashi, Y., Niki, Y., & Shimada, H. (2019). Relationship between daily and in-laboratory gait speed among healthy community-dwelling older adults. *Scientific reports*, 9(1), 1-6.

Tan, X., Chapman, C. D., Cedernaes, J., & Benedict, C. (2018). Association between long sleep duration and increased risk of obesity and type 2 diabetes: a review of possible mechanisms. *Sleep medicine reviews*, 40, 127-134.

Tay, J., Goss, A. M., Locher, J. L., Ard, J. D., & Gower, B. A. (2019). Physical function and strength in relation to inflammation in older adults with obesity and increased cardiometabolic risk. *The journal of nutrition, health & aging*, *23*(10), 949-957.

Taylor, D. (2014). Physical activity is medicine for older adults. *Postgraduate medical journal*, *90*(1059), 26-32.

Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Doré, J., ... & Tremblay, A. (2007). Reducing weight increases postural stability in obese and morbid obese men. *International journal of obesity*, 31(1), 153-160.

Terrier, P., & Reynard, F. (2015). Effect of age on the variability and stability of gait: a cross-sectional treadmill study in healthy individuals between 20 and 69 years of age. *Gait & posture*, 41(1), 170-174.

UK, G. (2019). UK Chief Medical Officers' physical activity guidelines.

Tieland, M., Trouwborst, I., & Clark, B. C. (2018). Skeletal muscle performance and ageing. *Journal of cachexia, sarcopenia and muscle*, 9(1), 3-19.

Togo, F., Watanabe, E., Park, H., Shephard, R. J., & Aoyagi, Y. (2005). Meteorology and the physical activity of the elderly: the Nakanojo Study. International journal of biometeorology, 50(2), 83-89.

Tomaz, S. A., Davies, J. I., Micklesfield, L. K., Wade, A. N., Kahn, K., Tollman, S. M., ... & Witham, M. D. (2020). Self-Reported Physical Activity in Middle-Aged and Older Adults in Rural South Africa: Levels and Correlates. *International journal of environmental research and public health*, 17(17), 6325.

Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-Cheung, A. E., ... & Chinapaw, M. J. (2017). Sedentary behaviour research network (SBRN)–terminology consensus project process and outcome. *International Journal of Behavioural Nutrition and Physical Activity*, 14(1), 1-17.

Tremblay, M. S., Colley, R. C., Saunders, T. J., Healy, G. N., & Owen, N. (2010). Physiological and health implications of a sedentary lifestyle. Applied physiology, nutrition, and metabolism, 35(6), 725-740.

Tripepi, G., Jager, K. J., Dekker, F. W., & Zoccali, C. (2010). Selection bias and information bias in clinical research. Nephron Clinical Practice, 115(2), c94-c99.

Troiano, R. P., Berrigan, D., Dodd, K. W., Masse, L. C., Tilert, T., & McDowell, M. (2008). Physical activity in the United States measured by accelerometer. *Medicine and science in sports and exercise*, 40(1), 181.

Trombetti, A., Reid, K. F., Hars, M., Herrmann, F. R., Pasha, E., Phillips, E. M., & Fielding, R. A. (2016). Age-associated declines in muscle mass, strength, power, and physical performance: impact on fear of falling and quality of life. *Osteoporosis international*, *27*(2), 463-471.

Tsagari A. (2020). Dietary protein intake and bone health. Journal of frailty, sarcopenia and falls, 5(1), 1–5.

Tsekoura, M., Kastrinis, A., Katsoulaki, M., Billis, E., & Gliatis, J. (2017). Sarcopenia and its impact on quality of life. *GeNeDis 2016*, 213-218.

Tucker, J. M., Welk, G. J., & Beyler, N. K. (2011). Physical activity in US adults: compliance with the physical activity guidelines for Americans. American journal of preventive medicine, 40(4), 454-461.

Tucker-Seeley, R. D., Subramanian, S. V., Li, Y., & Sorensen, G. (2009). Neighborhood safety, socioeconomic status, and physical activity in older adults. *American journal of preventive medicine*, 37(3), 207-213.

United Nations (UN). Department of Economic and Social Affairs Sustainable Development. Available online from: https://sdgs.un.org/goals/goal3 (accessed on May 7, 2021).

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Ageing 2019: Highlights (ST/ESA/SER.A/430).

Valenti, G., Bonomi, A. G., & Westerterp, K. R. (2016). Walking as a contributor to physical activity in healthy older adults: 2 week longitudinal study using accelerometry and the doubly labeled water method. *JMIR mHealth and uHealth*, 4(2), e5445.

Van Cauwenberg, J., Nathan, A., Barnett, A., Barnett, D. W., & Cerin, E. (2018). Relationships between neighbourhood physical environmental attributes and older adults' leisure-time physical activity: a systematic review and meta-analysis. *Sports medicine*, 48(7), 1635-1660.

van Leeuwen, W., Sallinen, M., Virkkala, J., Lindholm, H., Hirvonen, A., Hublin, C., ... & Härmä, M. (2018). Physiological and autonomic stress responses after prolonged sleep restriction and subsequent recovery sleep in healthy young men. Sleep and biological rhythms, 16(1), 45-54.

Van Dyck, D., Barnett, A., Van Cauwenberg, J., Zhang, C. J., Sit, C. H., & Cerin, E. (2020). Main and interacting effects of physical activity and sedentary time on older adults' BMI: The moderating roles of socio-demographic and environmental attributes. *PloS one*, *15*(7), e0235833.

Veen, J., Montiel-Rojas, D., Nilsson, A., & Kadi, F. (2021). Engagement in muscle-strengthening activities lowers sarcopenia risk in older adults already adhering to the aerobic physical activity guidelines. International Journal of Environmental Research and Public Health, 18(3), 989.

Verghese, J., Wang, C., Lipton, R. B., Holtzer, R., & Xue, X. (2007). Quantitative gait dysfunction and risk of cognitive decline and dementia. *Journal of Neurology, Neurosurgery & Psychiatry*, 78(9), 929-935.

Vernooij, C. A., Rao, G., Berton, E., Retornaz, F., & Temprado, J. J. (2016). The Effect of Aging on Muscular Dynamics Underlying Movement Patterns Changes. *Frontiers in aging neuroscience*, 8, 309.

Vincent, H. K., Vincent, K. R., & Lamb, K. M. (2010). Obesity and mobility disability in the older adult. *Obesity reviews*, 11(8), 568-579.

Visser, M., Goodpaster, B. H., Kritchevsky, S. B., Newman, A. B., Nevitt, M., Rubin, S. M., ... & Harris, T. B. (2005). Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *60*(3), 324-333.

Wang, D., Ruan, W., Peng, Y., & Li, W. (2018). Sleep duration and the risk of osteoporosis among middle-aged and elderly adults: a dose-response meta-analysis. *Osteoporosis International*, *29*(8), 1689-1695.

Wang, H., Abbas, K. M., Abbasifard, M., Abbasi-Kangevari, M., Abbastabar, H., Abd-Allah, F., ... & Damiani, G. (2020). Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–2019: a comprehensive demographic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258), 1160-1203.

Wang, H., Hai, S., Liu, Y., Liu, Y., & Dong, B. (2019). Skeletal muscle mass as a mortality predictor among nonagenarians and centenarians: a prospective cohort study. *Scientific reports*, *9*(1), 1-7.

Wannamethee, S. G., & Atkins, J. L. (2015). Muscle loss and obesity: the health implications of sarcopenia and sarcopenic obesity. *Proceedings of the Nutrition Society*, *74*(4), 405-412.

Wannamethee, S. G., Shaper, A. G., Lennon, L., & Whincup, P. H. (2007). Decreased muscle mass and increased central adiposity are independently related to mortality in older men. *The American journal of clinical nutrition*, *86*(5), 1339-1346.

Webber, S. C., Porter, M. M., & Menec, V. H. (2010). Mobility in older adults: a comprehensive framework. *The gerontologist*, 50(4), 443-450.

Welch, A., Hayhoe, R., & Cameron, D. (2020). The relationships between sarcopenic skeletal muscle loss during ageing and macronutrient metabolism, obesity and onset of diabetes. *Proceedings of the Nutrition Society*, *79*(1), 158-169.

Welk, G. (2002). Physical activity assessments for health-related research. Human Kinetics.

Wennie Huang, W. N., Perera, S., VanSwearingen, J., & Studenski, S. (2010). Performance measures predict onset of activity of daily living difficulty in community-dwelling older adults. *Journal of the American Geriatrics Society*, 58(5), 844-852.

White, D. K., Neogi, T., Nevitt, M. C., Peloquin, C. E., Zhu, Y., Boudreau, R. M., ... & Zhang, Y. (2013). Trajectories of gait speed predict mortality in well-functioning older adults: the Health, Aging and Body Composition study. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 68(4), 456-464.

Williams, J. M., Kay, D. B., Rowe, M., & McCrae, C. S. (2013). Sleep discrepancy, sleep complaint, and poor sleep among older adults. Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 68(5), 712-720.

Wilson, J. J., Blackburn, N. E., O'Reilly, R., Kee, F., Caserotti, P., & Tully, M. A. (2019). Association of objective sedentary behaviour and self-rated health in English older adults. *BMC research notes*, *12*(1), 1-6.

Wilson, J. J., McMullan, I., Blackburn, N. E., Skjødt, M., Caserotti, P., Giné-Garriga, M., ... & Tully, M. A. (2021). Associations of sedentary behaviour bouts with community-dwelling older adults' physical function. *Scandinavian Journal of Medicine & Science in Sports*, *31*(1), 153-162.

Wolf, M. S., Gazmararian, J. A., & Baker, D. W. (2005). Health literacy and functional health status among older adults. Archives of internal medicine, 165(17), 1946-1952.

Woo, T., Yu, S., & Visvanathan, R. (2016). Systematic Literature Review on the Relationship Between Biomarkers of Sarcopenia and Quality of Life in Older People. *The Journal of frailty & aging*, *5*(2), 88-99.

World Bank. New World Bank Country Classifications by Income Level: 2020–2021; World Bank: Washington, DC, USA, 2020. Available online from: https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2020-2021 (accessed on January 15, 2021).

World Health Organization. (2011). Waist circumference and waist-hip ratio: report of a WHO expert consultation, Geneva, 8-11 December 2008.

World Health Organization. Obesity: Preventing and Managing the Global Epidemic; World Health Organization: Geneva, Switzerland, 1998; p. 276.

World Health Organization. (2020). WHO guidelines on physical activity and sedentary behaviour: web annex: evidence profiles.

Yakabe, M., Hosoi, T., Akishita, M., & Ogawa, S. (2020). Updated concept of sarcopenia based on muscle–bone relationship. *Journal of bone and mineral metabolism*, 38(1), 7-13.

Yasunaga, A., Shibata, A., Ishii, K., Koohsari, M. J., Inoue, S., Sugiyama, T., ... & Oka, K. (2017). Associations of sedentary behaviour and physical activity with older adults' physical function: an isotemporal substitution approach. *BMC geriatrics*, *17*(1), 1-7.

Yen, C. H., Ku, M. H., & Wang, C. Y. (2017). Self-reported sitting time is associated with decreased mobility in older adults. *Journal of Geriatric Physical Therapy*, 40(3), 167-173.

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement disorders: official journal of the Movement Disorder Society*, 23(3), 329–472.

Yorston, L. C., Kolt, G. S., & Rosenkranz, R. R. (2012). Physical Activity and Physical Function in Older Adults: The 45 and U p S tudy. *Journal of the American Geriatrics Society*, *60*(4), 719-725.

Zampieri, S., Pietrangelo, L., Loefler, S., Fruhmann, H., Vogelauer, M., Burggraf, S., ... & Kern, H. (2015). Lifelong physical exercise delays age-associated skeletal muscle decline. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *70*(2), 163-173.

Zawisza, K., Tobiasz-Adamczyk, B., Galas, A., & Brzyska, M. (2015). Sleep duration and mortality among older adults in a 22-year follow-up study: an analysis of possible effect modifiers. *European journal of ageing*, *12*(2), 119-129.

Zecevic, A. A., Salmoni, A. W., Speechley, M., & Vandervoort, A. A. (2006). Defining a fall and reasons for falling: comparisons among the views of seniors, health care providers, and the research literature. *The Gerontologist*, 46(3), 367-376.

Zengin, A., Jarjou, L. M., Prentice, A., Cooper, C., Ebeling, P. R., & Ward, K. A. (2018). The prevalence of sarcopenia and relationships between muscle and bone in ageing West-African Gambian men and women. *Journal of cachexia, sarcopenia and muscle*, *9*(5), 920-928.

Zhu, W., Cheng, Z., Howard, V. J., Judd, S. E., Blair, S. N., Sun, Y., & Hooker, S. P. (2020). Is adiposity associated with objectively measured physical activity and sedentary behaviours in older adults?. *BMC geriatrics*, *20*(1), 1-8.

Zinkhan, M., Berger, K., Hense, S., Nagel, M., Obst, A., Koch, B., ... & Stang, A. (2014). Agreement of different methods for assessing sleep characteristics: a comparison of two actigraphs, wrist and hip placement, and self-report with polysomnography. Sleep medicine, 15(9), 1107-1114.

Appendix 1 - F statistics for gait parameters

1. Interaction effect for double support (%GC): $F(2, 78) = 7.82$, $p < 0.01$, partial $\eta^2 = .167$
    1. Main effect of age: $F(2, 78) = 4.02$, $p < 0.05$, partial $\eta^2 = .093$
    2. Main effect of surface: $F(1, 78) = 6.34$, $p < 0.05$, partial $\eta^2 = .075$

2. Interaction effect for stance (%GC): $F(2, 78) = 0.17$, $p = 0.85$, partial $\eta^2 = .004$
    1. Main effect of age: $F(2, 78) = 2.58$, $p = 0.08$, partial $\eta^2 = .082$
    2. Main effect of surface: $F(1, 78) = 0.15$, $p = 0.70$, partial $\eta^2 = .002$

3. Interaction effect for swing (%GC): $F(2, 78) = 0.81$, $p = 0.45$, partial $\eta^2 = .020$

1. Main effect of age: $F(2, 78) = 2.87$, $p = 0.06$, partial $\eta^2 = .069$
2. Main effect of surface: $F(1, 78) = 1.30$, $p = 0.26$, partial $\eta^2 = .016$

4. Interaction effect for stance time (s): $F(2, 78) = 0.29$, $p = 0.75$, partial $\eta^2 = .007$
    1. Main effect of age: $F(2, 78) = 7.82$, $p = 0.95$, partial $\eta^2 = .001$
    2. Main effect of surface: $F(1, 78) = 18.88$, $p < 0.01$ partial $\eta^2 = .191$

5. Interaction effect for swing time (s): $F(2, 80) = 0.77$, $p = 0.04$, partial $\eta^2 = .019$
    1. Main effect of age: $F(2, 78) = 9.61$, $p < 0.01$, partial $\eta^2 = .194$
    2. Main effect of surface: $F(1, 78) = 20.17$, $p < 0.01$, partial $\eta^2 = .201$

6. Interaction effect for stride time (s): $F(2, 78) = 0.32$, $p = 0.73$, partial $\eta^2 = .008$
    1. Main effect of age: $F(2, 78) = 2.55$, $p = 0.09$, partial $\eta^2 = .061$
    2. Main effect of surface: $F(1, 78) = 24.20$, $p < 0.01$, partial $\eta^2 = .237$

7. Interaction effect for CV double support phase (%): $F(2, 78) = 1.84$, $p = 0.17$, partial $\eta^2 = .045$
    1. Main effect of age: $F(2, 78) = 0.44$, $p = 0.64$, partial $\eta^2 = .011$
    2. Main effect of surface: $F(1, 78) = 47.46$, $p < 0.01$, partial $\eta^2 = .378$

8. Interaction effect for CV stance phase (%): $F(2, 78) = 2.35$, $p = 0.10$, partial $\eta^2 = .057$
    1. Main effect of age: $F(2, 78) = 1.16$, $p = 0.32$, partial $\eta^2 = .029$
    2. Main effect of surface: $F(1, 78) = 25.70$, $p < 0.01$, partial $\eta^2 = .248$

9. Interaction effect for CV swing phase (%): $F(2, 78) = 0.36$, $p = 0.70$, partial $\eta^2 = .009$
    1. Main effect of age: $F(2, 78) = 1.36$, $p = 0.26$, partial $\eta^2 = .034$
    2. Main effect of surface: $F(1, 78) = 15.94$, $p < 0.01$, partial $\eta^2 = .170$
10. Interaction effect for CV stride time (%) : $F(2, 78) = 2.86$, $p = 0.04$, partial $\eta^2 = .068$
    1. Main effect of age: $F(2, 78) = 2.25$, $p = 0.11$, partial $\eta^2 = .054$
    2. Main effect of surface: $F(1, 78) = 8.00$, $p < 0.01$, partial $\eta^2 = .093$

Appendix 2- F statistics for muscle activity

Interaction effect for loading phase

1. Gastrocnemius medialis $F(2, 77) = 1.50$, $p = 0.35$, partial $\eta^2 = .016$
   - **Main effect of age $F(2, 77) = 3.98$, $p < 0.05$, partial $\eta^2 = .094$**
   - Main effect of surface $F(1, 77) = 1.32$, $p = 0.70$, partial $\eta^2 = .007$
2. Gastrocnemius lateralis $F(2, 77) = 1.12$, $p = 0.80$, partial $\eta^2 = .117$
   - Main effect of age $F(2, 77) = 1.46$, $p = 0.24$, partial $\eta^2 = .036$
   - Main effect of surface $F(1, 77) = 1.46$, $p = 0.50$, partial $\eta^2 = .004$
3. Tibialis anterior $F(2, 77) = 1.19$, $p = 0.23$, partial $\eta^2 = .010$
   - Main effect of age $F(2, 77) = 2.73$, $p = 0.07$, partial $\eta^2 = .066$
   - Main effect of surface $F(1, 77) = 1.34$, $p = 0.50$, partial $\eta^2 = .003$
4. Vastus medialis $F(2, 77) = 1.58$, $p = 0.50$, partial $\eta^2 = .093$
   - Main effect of age $F(2, 77) = 1.35$, $p = 0.27$, partial $\eta^2 = .034$
   - Main effect of surface $F(1, 77) = 1.38$, $p = 0.64$, partial $\eta^2 = .031$
5. Vastus lateralis $F(2, 77) = 0.22$, $p = 0.18$, partial $\eta^2 = .043$
   - Main effect of age $F(2, 77) = 1.18$, $p = 0.31$, partial $\eta^2 = .030$
   - Main effect of surface $F(1, 77) = 1.73$, $p = 0.51$, partial $\eta^2 = .099$
6. Biceps femoris $F(2, 77) = 1.17$, $p = 0.36$, partial $\eta^2 = .074$
   - Main effect of age $F(2, 77) = 2.30$, $p = 0.11$, partial $\eta^2 = .056$
   - Main effect of surface $F(1, 77) = 1.39$, $p = 0.24$, partial $\eta^2 = .026$

Interaction effect for mid stance phase

1. Gastrocnemius medialis $F(2, 77) = 2.30$, $p = 0.55$, partial $\eta^2 = .027$
   - Main effect of age $F(2, 77) = 1.88$, $p = 0.40$, partial $\eta^2 = .075$
   - Main effect of surface $F(1, 77) = 1.02$, $p = 0.70$, partial $\eta^2 = .003$
2. Gastrocnemius lateralis $F(2, 77) = 2.23$, $p = 0.30$, partial $\eta^2 = .121$
   - Main effect of age $F(2, 77) = 1.23$, $p = 0.32$, partial $\eta^2 = .045$
   - Main effect of surface $F(1, 77) = 1.16$, $p = 0.41$, partial $\eta^2 = .023$
3. Tibialis anterior $F(2, 77) = 1.36$, $p = 0.43$, partial $\eta^2 = .021$
   - Main effect of age $F(2, 77) = 2.43$, $p = 0.08$, partial $\eta^2 = .063$
   - Main effect of surface $F(1, 77) = 1.14$, $p = 0.70$, partial $\eta^2 = .007$
4. Vastus medialis $F(2, 77) = 1.58$, $p = 0.57$, partial $\eta^2 = .034$
   - **Main effect of age $F(2, 77) = 4.39$ $p < 0.05$, partial $\eta^2 = .102$**

- Main effect of surface $F(1, 77) = 1.34$, $p = 0.37$, partial $\eta^2 = .002$

5. Vastus lateralis $F(2, 77) = 0.74$, $p = 0.09$, partial $\eta^2 = .084$
    - **Main effect of age $F(2, 77) = 9.13$, $p < 0.01$, partial $\eta^2 = .192$**
    - Main effect of surface $F(1, 77) = 0.33$, $p = 0.71$, partial $\eta^2 = .029$
6. Biceps femoris $F(2, 77) = 0.17$, $p = 0.85$, partial $\eta^2 = .044$
    - Main effect of age $F(2, 77) = 1.30$, $p = 0.21$, partial $\eta^2 = .023$
    - Main effect of surface $F(1, 77) = 1.18$, $p = 0.32$, partial $\eta^2 = .024$

Interaction effect for terminal stance phase

1. Gastrocnemius medialis $F(2, 77) = 0.70$, $p = 0.75$, partial $\eta^2 = .013$
    - Main effect of age $F(2, 77) = 0.81$, $p = 0.60$, partial $\eta^2 = .025$
    - Main effect of surface $F(1, 77) = 1.02$, $p = 0.20$, partial $\eta^2 = .031$
2. Gastrocnemius lateralis $F(2, 77) = 1.23$, $p = 0.30$, partial $\eta^2 = .171$
    - Main effect of age $F(2, 77) = 0.15$, $p = 0.71$, partial $\eta^2 = .025$
    - Main effect of surface $F(1, 77) = 1.06$, $p = 0.31$, partial $\eta^2 = .013$
3. Tibialis anterior $F(2, 77) = 0.76$, $p = 0.81$, partial $\eta^2 = .017$
    - Main effect of age $F(2, 77) = 1.56$, $p = 0.07$, partial $\eta^2 = .054$
    - Main effect of surface $F(1, 77) = 0.14$, $p = 0.70$, partial $\eta^2 = .009$
4. Vastus medialis $F(2, 77) = 0.61$, $p = 0.55$, partial $\eta^2 = .015$
    - **Main effect of age $F(2, 77) = 9.95$ $p < 0.01$, partial $\eta^2 = .205$**
    - Main effect of surface $F(1, 77) = 0.84$, $p = 0.59$, partial $\eta^2 = .043$
5. Vastus lateralis $F(2, 77) = 0.54$, $p = 0.22$, partial $\eta^2 = .051$
    - Main effect of age $F(2, 77) = 1.13$, $p = 0.13$, partial $\eta^2 = .072$
    - Main effect of surface $F(1, 77) = 0.21$, $p = 0.81$, partial $\eta^2 = .019$
6. Biceps femoris $F(2, 77) = 0.27$, $p = 0.66$, partial $\eta^2 = .031$
    - Main effect of age $F(2, 77) = 1.21$, $p = 0.09$, partial $\eta^2 = .075$
    - Main effect of surface $F(1, 77) = 1.18$, $p = 0.21$, partial $\eta^2 = .053$

Interaction effect for initial swing phase

1. Gastrocnemius medialis $F(2, 77) = 0.70$, $p = 0.75$, partial $\eta^2 = .033$
    - Main effect of age $F(2, 77) = 1.92$, $p = 0.41$, partial $\eta^2 = .065$
    - Main effect of surface $F(1, 77) = 1.02$, $p = 0.61$, partial $\eta^2 = .051$
2. Gastrocnemius lateralis $F(2, 77) = 1.12$, $p = 0.40$, partial $\eta^2 = .078$
    - Main effect of age $F(2, 77) = 1.22$, $p = 0.38$, partial $\eta^2 = .081$

- Main effect of surface $F(1, 77) = 0.76$, $p = 0.61$, partial $\eta^2 = .021$

3. Tibialis anterior $F(2, 77) = 0.86$, $p = 0.23$, partial $\eta^2 = .034$
    - Main effect of age $F(2, 77) = 1.22$, $p = 0.10$, partial $\eta^2 = .081$
    - Main effect of surface $F(1, 77) = 0.14$, $p = 0.70$, partial $\eta^2 = .009$
4. Vastus medialis $F(2, 77) = 8.88$, $p = 0.09$, partial $\eta^2 = .061$
    - **Main effect of age $F(2, 77) = 4.91$ $p < 0.05$, partial $\eta^2 = .113$**
    - Main effect of surface $F(1, 77) = 0.44$, $p = 0.34$, partial $\eta^2 = .007$
5. Vastus lateralis $F(2, 77) = 1.12$, $p = 0.08$, partial $\eta^2 = .091$
    - Main effect of age $F(2, 77) = 0.98$, $p = 0.12$, partial $\eta^2 = .075$
    - Main effect of surface $F(1, 77) = 0.21$, $p = 0.73$, partial $\eta^2 = .022$
6. Biceps femoris $F(2, 77) = 0.21$, $p = 0.88$, partial $\eta^2 = .024$
    - Main effect of age $F(2, 77) = 1.10$, $p = 0.21$, partial $\eta^2 = .043$
    - Main effect of surface $F(1, 77) = 1.11$, $p = 0.22$, partial $\eta^2 = .034$

Interaction effect for mid swing phase

1. Gastrocnemius medialis $F(2, 77) = 2.44$, $p = 0.09$, partial $\eta^2 = .060$
    - Main effect of age $F(2, 77) = 0.58$, $p = 0.56$, partial $\eta^2 = .075$
    - Main effect of surface $F(1, 77) = 1.02$, $p = 0.80$, partial $\eta^2 = .007$
2. Gastrocnemius lateralis $F(2, 77) = 0.36$, $p = 0.70$, partial $\eta^2 = .009$
    - Main effect of age $F(2, 77) = 2.09$, $p = 0.13$, partial $\eta^2 = .052$
    - Main effect of surface $F(1, 77) = 1.35$, $p = 0.08$, partial $\eta^2 = .097$
3. Tibialis anterior $F(2, 77) = 049$, $p = 0.62$, partial $\eta^2 = .012$
    - Main effect of age $F(2, 77) = 0.49$, $p = 0.61$, partial $\eta^2 = .012$
    - Main effect of surface $F(1, 77) = 1.72$, $p = 0.70$, partial $\eta^2 = .009$
4. Vastus medialis $F(2, 77) = 0.08$, $p = 0.92$, partial $\eta^2 = .002$
    - Main effect of age $F(2, 77) = 0.84$ $p = 0.92$, partial $\eta^2 = .002$
    - Main effect of surface $F(1, 77) = 1.17$, $p = 0.57$, partial $\eta^2 = .099$
5. Vastus lateralis $F(2, 77) = 1.34$, $p = 0.27$, partial $\eta^2 = .034$
    - Main effect of age $F(2, 77) = 1.34$, $p = 0.27$, partial $\eta^2 = .034$
    - Main effect of surface $F(1, 77) = 0.84$, $p = 0.28$, partial $\eta^2 = .019$
6. Biceps femoris $F(2, 77) = 0.42$, $p = 0.66$, partial $\eta^2 = .011$
    - Main effect of age $F(2, 77) = 0.42$, $p = 0.66$ partial $\eta^2 = .011$
    - Main effect of surface $F(1, 77) = 1.82$, $p = 0.39$, partial $\eta^2 = .098$

Interaction effect for terminal swing phase

1. Gastrocnemius medialis $F(2, 77) = 0.45$, $p = 0.64$, partial $\eta^2 = .012$
    - Main effect of age $F(2, 77) = 3.06$, $p = 0.06$, partial $\eta^2 = .074$
    - Main effect of surface $F(1, 77) = 1.12$, $p = 0.90$, partial $\eta^2 = .005$
2. Gastrocnemius lateralis $F(2, 77) = 0.88$, $p = 0.41$, partial $\eta^2 = .022$
    - Main effect of age $F(2, 77) = 2.63$, $p = 0.08$, partial $\eta^2 = .064$
    - Main effect of surface $F(1, 77) = 0.62$, $p = 0.08$, partial $\eta^2 = .007$
3. Tibialis anterior $F(2, 77) = 0.08$, $p = 0.93$, partial $\eta^2 = .002$
    - Main effect of age $F(2, 77) = 1.08$, $p = 0.35$, partial $\eta^2 = .027$
    - Main effect of surface $F(1, 77) = 0.66$, $p = 0.82$, partial $\eta^2 = .009$
4. Vastus medialis $F(2, 77) = 1.22$, $p = 0.30$, partial $\eta^2 = .031$
    - Main effect of age $F(2, 77) = 0.75$, $p = 0.47$, partial $\eta^2 = .019$
    - Main effect of surface $F(1, 77) = 0.70$ $p = 0.57$, partial $\eta^2 = .008$
5. Vastus lateralis $F(2, 77) = 0.74$, $p = 0.48$, partial $\eta^2 = .019$
    - Main effect of age $F(2, 77) = 0.31$, $p = 0.74$, partial $\eta^2 = .008$
    - Main effect of surface $F(1, 77) = 0.52$, $p = 0.43$, partial $\eta^2 = .095$
6. Biceps femoris $F(2, 77) = 0.44$, $p = 0.65$, partial $\eta^2 = .011$
    - Main effect of age $F(2, 77) = 1.28$, $p = 0.28$, partial $\eta^2 = .032$
    - Main effect of surface $F(1, 77) = 0.45$, $p = 0.74$, partial $\eta^2 = .004$

Appendix 3- South African and Scottish questionnaires

South African version

<u>LIFESTYLE QUESTIONNAIRE</u>

<u>DEMOGRAPHIC AND SOCIOECONOMIC DETAILS</u>

1. How many people living in your household, including you?______________________

2. How many rooms do you have in your house (including kitchen, lounge, dining room, bedrooms)?_________________

3. In your home, how many rooms are there just for sleeping?_____________________

4. How would you describe your home (tick the one that best describes it)?

House		Flat/Cottage/Townhouse		Residence/hostel	
Shack/Zozo		Government housing (e.g. municipal/RDP housing)		Room in backyard of house (or shared house)	

5. What type of household water do you h access to?

Running water (tap water)		Protected dug out well		Public tap/standpipe	
Piped water into yard/plot		Unprotected dug well		Tanker truck/cart with small tank	
Surface water		Protected spring		Rain water	

6. What type of toilet do you have?

Flush to piped sewer system		Protected dug out well		Bucket system	
Flush to septic tank		Ventilated improved pit (VIP) latrine		Other	
Traditional pit toilet		No facility or bush or field			

7. Which of the following do you have in your household at the present time?

	YES	**NO**		**YES**	**NO**
Electricity			Telephone		
Television			Video machine		
Radio			Microwave		

Motor vehicle			Computer		
Fridge			Cellular telephone		
Stove and oven			Mnet		
Washing machine			DSTV		

8. Marital status:

Single		Divorced/separated	
Married		Widowed	
Living with partner, not married			

9. How many children do you have?______________________________________

10. What are the ages of the children? ____________________________________
11. Education (last standard passed):

No formal education		Std 8 (Grade 10)	
Sub A/B (Grade 1-2)		Std 9 (Grade 11)	
Std 1-3 (Grade 3-5)		Matric (Grade 12)	
Std 4-5 (Grade 6-7)		Tertiary education	
Std 6-7 (Grade 8-9)		Other	

Are you:

Employed		A student	
Unemployed		Informal	
Other:			

12. If employed, What work do you do?____

13. Monthly Household Income:

R0 to 2500		R10 000 to 15000	
R 2500 to 5000		R15000 to 20000	
R5000 to 7500		R20000 to R30000	
R7500 to 10 000		Other range:	

14. How many people do you support with this income? ________Adults ______ Children:

15. What language do you speak at home?
____

16. Do you own a car? YES NO

17. QUALITY OF LIFE AND CLINICAL CONDITIONS

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
1	Would you say your health is poor, average, good, or very good/excellent ?	POOR .... 1 AVERAGE .... 2 GOOD... 3 VERY GOOD/EXCELLENT......................... 4	
2	Do you personally think that you are underweight, normal weight or overweight?	UNDERWEIGHT...1 NORMAL WEIGHT ....2 OVERWEIGHT..3 DON'T KNOW...8	
3	Has a **doctor** or **nurse** or **health worker** at a **clinic** or at **hospital told you** that you had or have any of the following conditions:		
3A	High Blood Pressure?	YES... 1 NO .... 2 DON'T KNOW.. 8	
3B	Heart attack or angina (chest pains)?	YES... 1 NO .... 2 DON'T KNOW.. 8	
3C	Stroke?	YES... 1 NO .... 2 DON'T KNOW.. 8	

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
3D	High blood cholesterol or fats in the blood?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3E	Diabetes or Blood Sugar?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3F	Emphysema/Bronchitis?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3G	Asthma?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3H	Sore joints, e.g. Arthritis, gout?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3I	Osteoporosis?	YES.. 1 NO .... 2 DON'T KNOW.. 8	

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
3J	Epilepsy / fits?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3K	TB?	YES.. 1 NO .... 2 DON'T KNOW.. 8	
3L	How many episodes of TB have you ever been treated for?	NUMBER OF TB EPISODES……….. Are you currently on TB medications? …………………………. When was your last TB episode: …………………………………	

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
3M	Cancer? Do you have any other conditions or disorders that haven't been mentioned?	YES.. 1 NO .... 2 DON'T KNOW... 8 If yes, what type and location? Provide details	

18. HEALTH KNOWLEDGE

Do you know your HIV status?	YES..1 NO..2

If yes, are you:	Positive ....1 Negative ....2 Unwilling to disclose
Have you had your blood pressure measured in the past 12 months?	YES....1 NO....2
Do you know what your blood pressure is?	YES....1 NO....2
Is it high, normal or low?	HIGH....1 NORMAL....2 LOW....3 DON'T KNOW....8

19. MEDICATIONS

Do you use any medicine regularly or daily that a doctor or nurse has prescribed?	YES....1 NO ....2 DON'T KNOW....8
How many different medicines do you use regularly (more than once a month)?	NUMBER____________ | | |
Who pays for most of the medication, prescribed by a doctor or nurse, that you use? **(READ THE OPTIONS)**	RESPONDENT ....☐ FAMILY ....☐ MEDICAL AID ....☐ PROVIDED AT CLINIC OR PUBLIC HOSPITAL ....☐ EMPLOYER ....☐

	OTHER _ ☐ (SPECIFY)

MEDICATION & SUPPLEMENT USE

Do you use nutritional or other supplements?	YES .... NO ....
If YES, name the supplement, what is it used for, dosage, frequency and duration of use.	
Do you use any herbal medicine?	YES .... NO ....
Name of herbal medicine, what you are using for, state the dosage, frequency and duration of use.	
Have you been sick in the past month?	YES .... NO ....
If YES, what sickness?	

8.9.1 Did you take medicine? (yes/no box) What medication(s) did you take? State the dosage, frequency and duration of use.	

Scottish version

DEMOGRAPHIC AND SOCIOECONOMIC DETAILS

1. How many people living in your household, including you?
   ____

2. How many rooms do you have in your house (including kitchen, lounge, dining room, bedrooms)? _________________

3. In your home, how many rooms are there just for sleeping?
   ____

4. How would you describe your home (tick the one that best describes it)?

House		Flat/Cottage/Townhouse		Residence	
		Government housing (e.g. municipal)			

5. Which of the following do you have in your household at the present time?

	YES	NO		YES	NO
Electricity			Telephone		
Television			Video machine		
Radio			Microwave		

Motor vehicle			Computer		
Fridge			Cellular telephone		
Stove and oven			Washing machine		

6. Marital status:

Single (never married)		Divorced	
Married		Widowed	
Living with partner, as if married		Civil Partnership	
Separated			

7. How many children do you have? ______________________________________

8. What are the ages of the children? ____________________________________

9. Education (highest level completed):

Some primary (not complete)		HNC/HND or equivalent	
Primary or equivalent		First degree	
O level/O grade or equivalent		Postgraduate/higher degree	
Higher or equivalent		None	
Sixth year studies or equivalent		Other	

10. Which one of these would you say best describes your current situation?

Retired		Permanently sick or disabled	
Employed (including unpaid work in		Looking after home or	

family business, employment programme)		family	
Self-employed		In education or training	
Unemployed			
Other (please specify):			

11. If employed, what is the name or title of your job?

____

12. Before any deduction for tax, national insurance or pension and health contributions, union subscriptions and so on, which of the following best describes what your typical wage/salary payment amounted to? Include regular overtime, commission, tips etc.

Less than £300		More than £1150, less than £1250	
More than £300, less than £450		More than £1250, less than £1900	
More than £450, less than £600		More than £1900, less than £2500	
More than £600, less than £900		More than £2500	
More than £900, less than £1150		Other	

13. How many people do you support with this income?

________Adults ______ Children

14. What language do you speak at home?

____

15. Do you own a car? YES NO

16. Quality of life and clinical conditions

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
1	Would you say your health is poor, average, good, or very good/excellent ?	POOR .... 1 AVERAGE .... 2 GOOD .... 3 VERY GOOD/EXCELLENT 4	
2	Do you personally think that you are underweight, normal weight or overweight?	UNDERWEIGHT .... 1 NORMAL WEIGHT .... 2 OVERWEIGHT .... 3 DON'T KNOW 8	
3	Has a **doctor** or **nurse** or **health worker** at a **clinic** or at **hospital told you** that you had or have any of the following conditions:		
3A	High Blood Pressure?	YES .... 1 NO .... 2 DON'T KNOW 8	
3B	Heart attack or angina (chest pains)?	YES .... 1 NO .... 2 DON'T KNOW 8	
3C	Stroke?	YES .... 1 NO .... 2 DON'T KNOW 8	
3D	High blood cholesterol or fats in the blood?	YES .... 1 NO .... 2 DON'T KNOW 8	
3E	Diabetes or Blood Sugar?	YES .... 1 NO .... 2 DON'T KNOW 8	
3F	Emphysema/Bronchitis?	YES .... 1 NO .... 2 DON'T KNOW 8	

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
3G	Asthma?	YES.. 1 NO .... 2 DON'T KNOW... 8	
3H	Sore joints, e.g. Arthritis, gout?	YES.. 1 NO .... 2 DON'T KNOW... 8	
3I	Osteoporosis?	YES.. 1 NO .... 2 DON'T KNOW... 8	
3J	Epilepsy / fits?	YES.. 1 NO .... 2 DON'T KNOW... 8	
3K	TB?	YES.. 1 NO .... 2 DON'T KNOW... 8	
3L	Cancer?	YES.. 1 NO .... 2 DON'T KNOW... 8 If yes, what type and location?	
	Do you have any other conditions or disorders that haven't been mentioned?	<u>Provide details</u>	

17. Health knowledge

Have you had your blood pressure measured in the past 12 months?	YES .... 1 NO 2
Do you know what your blood pressure is?	YES .... 1 NO 2
Is it high, normal or low?	HIGH.. 1 NORMAL .... 2 LOW .... 3 DON'T KNOW.. 4

18. Medications

Do you use any medicine regularly or daily that a doctor or nurse has prescribed?	YES ....1 NO...2 DON'T KNOW 8
How many different medicines do you use regularly (more than once a month)?	NUMBER_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

MEDICATION & SUPPLEMENT USE

Do you use nutritional or other supplements?	YES .... NO ....
If YES, name the supplement, what is it used for, dosage, frequency and duration of use.	
Do you use any herbal medicine?	YES .... NO ....
Name of herbal medicine, what you are using for, state the dosage, frequency and duration of use.	
Have you been sick in the past month?	YES .... NO ....
If YES, what sickness? 8.9.1 Did you take medicine? (yes/no box) What medication(s) did you take? State the dosage, frequency	

and duration of use.	

Appendix 4 – Pittsburgh Sleep Quality Index

PITTSBURGH SLEEP QUALITY INDEX

1. Over the past months, what time have you usually gone to bed?________________________
2. Over the past month, how long has it usually taken for you to fall asleep each night?_____________min
3. Over the past month, what time have you gotten up in the morning?______________________
4. Over the past month, how many hours of actual SLEEP (i.e. not the number of hours in bed) did you get per night?____

5.During the past month, how often have you had trouble sleeping because you	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				

j. Other reason; please describe, including how often you have had trouble sleeping because of this reason(s)				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality overall?				

10. Have you had trouble sleeping because of any other reasons? YES NO

If YES, please

describe____

____

__

11. In the past month, how often have you had trouble sleeping because of these reasons?

____

____

____

Appendix 5 – Sleep diary

SLEEP LOG FORM

Code: ______________ **Name:** _________________________ **Issue Date:**

Return Date:

DAY	DATE	WAKE UP TIME	SLEEPING TIME
DAY 0 (Example)	**23/02/2016**	**8:15am**	**10:46pm**
Day 1			
Day 2			
Day 3			
Day 4			
Day 5			
Day 6			
Day 7			
Day 8			

INSTRUCTIONS:

- Please wear all the equipment from the date of issue until the last date stated on this form.
- Only remove the equipment during bathing/ shower. Otherwise, the equipment should be worn all day long, including sleeping time.
- Please only Log in the time you wake up in the morning (open your eyes in the morning) and sleep (closing your eyes for sleep at night).

Appendix 6 - Activity log diary from a Scottish male aged 75 years old

ID100

DATE	TIME START	TIME END	ACTIVITY
7/2/20	13.00	14.10	Preparing & eating lunch, washing up
	14.10	15.15	Out in town - driving, walking etc
	15.15	16.45	Sleeping
	16.45	17.30	Normal flat activity
	17.30	19.45	Preparing & eating dinner, washing up
	19.45	22.00	Watching TV, relaxing
	22.00	23.00	Reading
	23.05		Sleep
8/2/20	06.00		Up for toilet briefly
	08.00	09.20	Wake up & start morning routine
	09.20	09.55	Showering etc Sensors off
	09.55		Sensors back on
	09.55	10.30	About the flat
	10.30	11.25	Out for messages - driving, walking, sitting
	11.25	12.50	About the flat & lunch
	12.50	15.30	Outing to Crieff
	15.30	18.15	At home relaxing + normal activities
	18.15	19.25	Dinner prep + eating + washing up
	19.25	22.30	Watching TV
	22.30	23.25	Reading
	23.30		Sleep
9/2/20	04.20		Up briefly for toilet
	07.50	09.30	Wake up & start morning routine
	09.30	10.10	Showering etc Sensors off
	10.10		Sensors back on
	10.10	23.25	About the flat having a less active day
	23.30		Sleep

ID 100

DATE	TIME		ACTIVITY
	START	END	
10/2/20	06.30		Up briefly for toilet
	07.00	08.50	Wake up + start morning routine
	08.50	09.12	Showering so sensors off
	09.12		Sensors back on
	09.12	approx 10.05	Preparing to go out
	10.05	11.15	Shopping (walk into town)
	11.15	12.45	On computer + other admin
	12.45	14.00	Preparing + having lunch + washing up
	14.00	15.30	More admin
	15.30	16.10	Resting, v tired
	16.10	16.30	Walk to post letter
	16.30	17.30	Just doing minor things in the flat
	17.30	19.20	Preparing evening meal, eating, washing up
	19.20	22.05	Watching TV
	22.05	22.55	Reading
	23.00		Sleep
11/02/20	06.50	07.55	Wake up + start morning routine
	07.55	08.30	Showering so sensors off
	08.30		Sensors back on
	08.30	08.50	Preparing to go out
	08.50	09.25	Drive to supermarket - shopping - drive home
	09.25	10.05	About the flat + preparing to go out
	10.05	11.45	Walking Grp meet - drive → walk → drive home
	11.45	12.40	In flat
	12.40	13.05	Drive to + from town
	13.05	14.10	Lunch prep + eat
	14.10	15.05	Shopping
	15.05	16.50	Resting v tired
	16.50	18.30	Jobs about the flat
	18.30	20.10	Prep, eating + washing up of dinner
	20.10	22.05	TV
	22.05	23.25	Reading
	23.30		Sleep

ID 100

DATE	TIME START	TIME END	ACTIVITY
12/2/20	04.40		Up briefly for toilet
	07.00	08.15	Wake up & start morning routine
	08.15	08.55	Sensors off & showering
	08.55	10.25	Sensors back on, Preparing for meeting
	10.25	12.45	Attending Probus meeting (walk there + back)
	12.45	14.15	Preparing lunch, eating + washing up
	14.15	14.30	Posting letter
	14.30	16.45	Resting.
	16.45	18.15	Various jobs around flat
	18.15	19.30	Preparing diner, eating + washing up
	19.30	22.10	Reading, watching TV
	22.10	23.15	Reading
	23.20		Sleep
13/2/20	04.35		Up briefly for toilet
	07.15	08.10	Wake up & start morning routine + breakfast
	08.10	08.46	Sensors off & showering
	08.45	09.20	Sensors back on. Preparing for appointment
	09.20	11.45	Appointment in Dunblane, then shopping
	11.45	13.40	Unpacking shopping, preparing lunch + having
	13.40	14.00	Walk to centre then onto physio appointment
	14.00	14.55	Physio appointment (ActiGraph monitor OFF)
	14.55	15.30	ActiGraph monitor ON Walk home
	15.30	17.30	At home
	17.30	19.00	Preparing diner, eating + washing up
	19.00	22.00	Reading + watching TV
	22.00	22.55	Reading
	23.00		Sleep
14/2/20	04.50		Up briefly for toilet
	06.00		Wake up & start morning routine + breakfast
	06.50	07.25	Sensors off + showering
	07.25		Sensors back on outside of clothes
			Driving to University

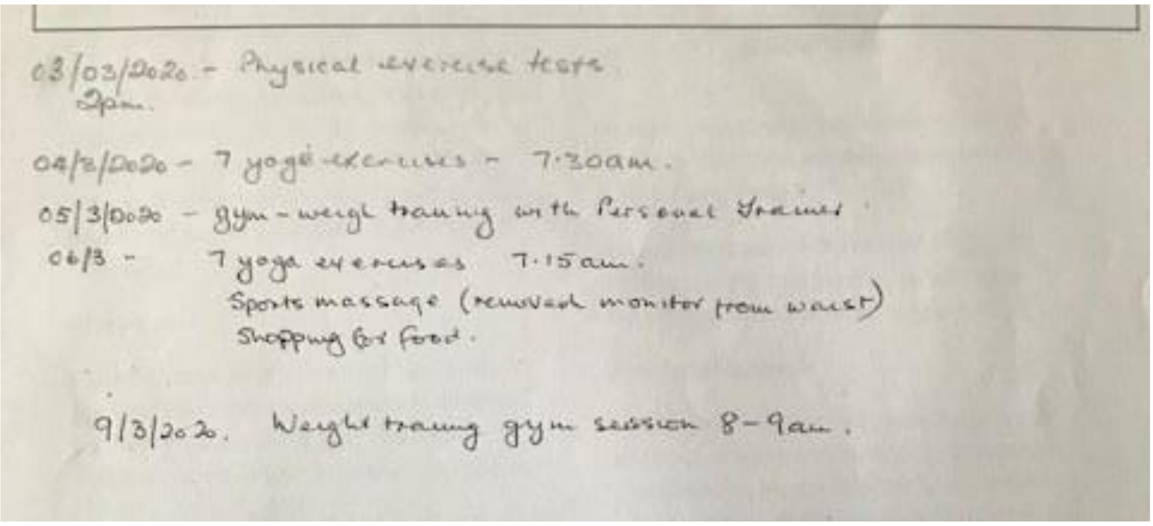
Appendix 7 - Activity log diary from a Scottish male aged 71 years old

EACH DAY — AT LEAST 1 DOG WALK LASTING
APPROX 1 HR.
TUESDAY + THURSDAY — 1 HR PILATES CLASS.
EACH DAY — MONITORS TAKEN OFF FOR 30-45 MINS
IN THE MORNING FOR A SHOWER.
7/2/20 — MONITORS TAKEN OFF ~5-6.30PM
FOR SWIMMING.

Appendix 8 - Activity log diary from a Scottish female aged 61 years old

Fri 28th
9-10.45 - gym + salsa class
- walk to + from gym (approx. 1 mile).
1.30-5.00 DIY - painting
6.30-7.30 Housework.
7.30-12.00 Reading / T.V.
Sat. 29th.
9.30-11.30 - DIY - painting.
11.30-12.15 - walk (2 miles).
1.00-3.00 - shopping / driving.
3.00-5.00 - housework.
5.00-8.00 - out at event.
8.00-10.30 - looking after children.
Sun 1st.
10.30-11.30 - shopping.
2.00-5.00 - DIY - painting
7.00-10.30 - reading / watching TV.
Mon. 2nd.
8.30-10.00 - housework.
1.00-3.00 - walk (3.5 miles).
3.30-5.30 - DIY - painting.
6.30-9.30 - reading / watching TV.
Tues. 3rd.
Working day - at work 8.00am - 3.30pm
5.30-7.00 - housework.
7.00/7.30 - 10.00 - reading / watching TV.

Appendix 9 - Activity log diary from a Scottish female aged 83 years old



03/03/2020 - Physical exercise tests
2pm.

04/3/2020 - 7 yoga exercises - 7:30am.

05/3/2020 - gym - weight training with Personal Trainer.

06/3 - 7 yoga exercises 7.15am.
Sports massage (removed monitor from waist)
Shopping for food.

9/3/2020. Weight training gym session 8-9am.

Publication

International Journal of *Environmental Research and Public Health*

MDPI

Article

Intensity Matters for Musculoskeletal Health: A Cross-Sectional Study on Movement Behaviors of Older Adults from High-Income Scottish and Low-Income South African Communities

Ilaria Pina [1,*], Amy E. Mendham [2,3], Simone A. Tomaz [4], Julia H. Goedecke [2,3], Lisa K. Micklesfield [2,3], Naomi E. Brooks [4], Iain J. Gallagher [4], Rachel Crockett [1], Paul Dudchenko [1] and Angus M. Hunter [4]

1 Department of Psychology, University of Stirling, Stirling FK9 4LA, UK; rachel.crockett@stir.ac.uk (R.C.); p.a.dudchenko@stir.ac.uk (P.D.)
2 MRC/Wits Developmental Pathways for Health Research Unit, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg 2000, South Africa; ae.mendham@uct.ac.za (A.E.M.); julia.goedecke@mrc.ac.za (J.H.G.); lisa.micklesfield@wits.ac.za (L.K.M.)
3 Division of Exercise Science and Sports Medicine, Department of Human Biology, University of Cape Town, Cape Town 7700, South Africa
4 Faculty of Health Science and Sport, University of Stirling, Stirling FK9 4LA, UK; tmzsim@gmail.com (S.A.T.); n.e.brooks@stir.ac.uk (N.E.B.); i.j.gallagher@stir.ac.uk (I.J.G.); a.m.hunter1@stir.ac.uk (A.M.H.)
* Correspondence: ilaria.pina@stir.ac.uk

check for updates

Citation: Pina, I.; Mendham, A.E.; Tomaz, S.A.; Goedecke, J.H.; Micklesfield, L.K.; Brooks, N.E.; Gallagher, I.J.; Crockett, R.; Dudchenko, P.; Hunter, A.M. Intensity Matters for Musculoskeletal Health: A Cross-Sectional Study on Movement Behaviors of Older Adults from High-Income Scottish and Low-Income South African Communities. *Int. J. Environ. Res. Public Health* 2021, *18*, 4310. https://doi.org/10.3390/ijerph18084310

Academic Editor: Paul B. Tchounwou

Received: 8 April 2021
Accepted: 15 April 2021
Published: 19 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: This study aimed to investigate differences in physical activity (PA) patterns and the associations between objectively measured 24-h movement behaviors and musculoskeletal measures (muscle strength, muscle mass, physical performance, and bone mineral density) in a high-income and a low-income community. This cross-sectional study recruited independent living older adults aged 60–85 years from high-income Scottish (n = 150) and low-income South African (n = 138) settings. Participants completed demographic and health questionnaires, and testing included body composition and bone mineral density (dual energy X-ray absorptiometry), physical performance (grip strength, gait speed), and PA (accelerometry). Participants accumulated similar amounts of weekly total PA, however, the Scottish cohort engaged in more moderate-to-vigorous intensity PA (MVPA) and sedentary behavior (SB), while the South African cohort spent more time sleeping and in light intensity PA (LPA). From compositional data analysis, more time spent in MVPA relative to the other movement behaviors was positively associated with higher muscle mass ($p < 0.001$) and strength ($p = 0.001$) in the Scottish cohort. Conversely, more time spent in MVPA was associated with faster gait speed ($p < 0.001$) and greater hip bone mineral density ($p = 0.011$) in the South African cohort. Our findings confirm the beneficial role of MVPA in both high- and low-income cohorts, however, the relationship MVPA had with components of musculoskeletal health in older adults differed between settings.

Keywords: sarcopenia; osteoporosis; ageing; compositional analysis; moderate-to-vigorous physical activity; bone mineral density; grip strength; gait speed; accelerometry; muscle mass

1. Introduction

The number of older adults and years lived with disabilities is increasing worldwide [1]. Primary features of ageing include decreased bone and muscle health, which contribute to reduced quality of life and loss of mobility [2]. Decreased bone mass and changes in bone integrity are referred to as osteoporosis, a condition associated with greater fracture risk and reduced mobility [3]. Sarcopenia is a progressive and generalized skeletal muscle disorder that affects physical functionality and is identified by low muscle strength, along with decreased muscle mass [4]. As such, osteoporosis and sarcopenia are common disorders in older adults and prevention strategies should be a main focus to maintain quality of life with ageing.

In older adults, regular physical activity (PA) can increase functional independence, enhance immunity (a critical factor in the current COVID-19 pandemic), reduce obesity, and improve metabolic health and overall quality of life [5–9]. Specifically, allocating more time to higher PA intensities (moderate-to-vigorous PA, MVPA) by reducing time in sedentary behavior (SB) or light PA (LPA) has demonstrated a positive impact on musculoskeletal components and subsequent reductions in sarcopenia [10] and osteoporosis [11] rates in older adults. Assessing PA and SB is important as low levels of PA are recognized as underlying mechanisms of sarcopenia and osteoporosis [12,13]. Recent studies investigated the crosstalk between muscle and bone tissues due to their shared role in movement activities [14]. This interplay between muscle and bone supports the idea that the mechanical load produced by PA via muscle contraction shapes bone structure and maintains bone mineral density (BMD) and bone integrity with ageing [15]. This evidence highlights the need to consider bone, skeletal muscle, and their crosstalk in research with a view to inform physical activity guidelines in older adults.

The World Health Organization (WHO) recently introduced PA and SB guidelines for people of all ages [16]. The guidelines for older adults now consider movement behaviors throughout the day. Older adults' PA patterns and intensities are often dictated by socioeconomic status, with differences shown between low- to middle-income countries (LMICs) and high-income countries (HICs) [17–19]. In HICs, there is easier access to facilities for leisure-time activities that include gym-based exercise and sports [20], which are activities associated with higher PA intensities, particularly MVPA [21]. Conversely, older adults in LMICs often accumulate PA through occupational and ambulatory activities typically completed at low intensities [22]. Notably, data from South African women indicate that in addition to high levels of LPA, there is also evidence of longer sleeping times (>9 h per night) associated with negative health outcomes [23]. Additionally, LMICs are often characterized by both a higher prevalence of obesity [24] and communicable and non-communicable diseases [25] compared to HICs [26]. Differences in living conditions and sociodemographic factors contribute to greater exposure and vulnerability of low socioeconomic communities to chronic diseases [27], leading to differences in general health status across socioeconomic settings. However, little is known on how differences in health status and movement behaviors in LMICs and HICs can affect the musculoskeletal health of men and women living in these settings.

In assessing movement behaviors, one faces methodological challenges that arise from the non-independence of these activity measures. Movement behaviors include all activities over a 24-h period across the movement spectrum, from no/little movement (sleep, SB) to movement of greater intensities (LPA and MVPA). Importantly, time spent in each movement behavior is related to the time spent in the other movement behaviors. Indeed, increasing the relative time spent in one behavior will result in a decrease in another as they are measured in a discrete period of time (24 h). However, the majority of statistical approaches used to analyze movement behaviors do not consider the 24-h period and the intrinsic collinearity of time use components. To address this in the current study, we used compositional data analysis (CoDa), which considers the co-dependence of movement behaviors [28].

Differences in movement behaviors between socioeconomic settings may suggest a different allocation of specific PA behaviors and represent an important target to improve research translation of behavior into context-specific population health. We had data for an LMIC (South Africa) and an HIC (Scotland). To date, no study has explicitly explored the relationship of all movement behaviors with muscle and bone integrity in older adults of similar age living in diverse settings in South Africa and Scotland. Further, there is limited research reporting objectively measured sleep in South African and Scottish older adults.

Accordingly, this study aimed to investigate differences in PA patterns and the associations between objectively measured 24-h movement behaviors and musculoskeletal outcomes (muscle strength, muscle mass, physical performance, and BMD), and their crosstalk, in representative samples of older adults from a high-income and a low-income country. On the basis of previous literature, we hypothesized that movement behaviors, particularly PA, would have a similar volume but would differ in intensity between older adults from high and low-income countries, with the high-income country displaying higher intensities of PA. Further, differences in health status and obesity prevalence may lead to different associations between physical activity patterns and musculoskeletal outcomes in high- and low-income communities.

2. Materials and Methods

In this cross-sectional study, a representative sample of Scottish older adults (n = 151) from a high-income urban setting and South African older adults (n = 154) from a low-income urban setting were recruited. These settings were categorized according to the World Bank classification [29]. Inclusion criteria were the same for the 2 cohorts: Participants were aged 60–85 years (older adult classification from the United Nations [30]), were ambulatory, living independently, and able to understand verbal and written information about the respective studies. Participants with diabetes were excluded from the Scottish study as this was required by the Scottish Ethics committee. The Scottish study was approved by the "West of Scotland Research Ethics Committee 3" (19/WS/0118). The South African study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (HREC REF:095/2018), and the NHS, Invasive or Clinical Research Committee at the University of Stirling (NICR:17/18). All participants provided verbal and written informed consent prior to commencing the study. The study was conducted in accordance with the 1964 Declaration of Helsinki and later amendments [31].

2.1. Study Design

Data collection protocols and methods for analysis were the same in the South African and Scottish studies unless otherwise stated. Participants from both samples were reimbursed for travel costs. Data were collected over 2 testing sessions (Figure 1). The first testing session was conducted over the course of 4 h, which included the following tests: demographic and health questionnaires. These included information on housing density (ratio of the number of people living in the house relative to the number of rooms) and smoking status (current and past smoking behaviors), as well as car ownership, civil status, employment, and sleep quality. Testing included body composition, BMD, hand grip strength, and gait speed, and objectively measured movement behaviors. Participants then attended a second testing session to return accelerometers after 7 days. In South Africa, data collection was undertaken by an exercise physiologist and 2 clinical research assistants. In Scotland, data collection was completed by a physiotherapist. In our final analysis (Figure 1), no participants were excluded in the Scottish sample (total n = 150), however, 12 older adults were excluded in the South African cohort due to the lack of valid accelerometry data (total n = 138).

2.2. Body Composition

Body mass was measured to the nearest 0.1 kg using a digital weighing scale (Scotland: Soehnle Connect, Soehnle-Waagen GmbH and Co.KG, Murrhardt, Germany; South Africa: BW-150, NAGATA, Tainan, Taiwan) in light-weight clothing without shoes, and height was assessed to the nearest 0.1 cm using a portable stadiometer (Scotland: Seca 213, Birmingham, UK; South Africa: 3PHTROD-WM, Detecto, MO, USA). Body mass index (BMI) was computed as body mass (kg)/height (m^2) and classified according to World Health Organization (WHO) criteria [32].

Whole and subtotal (whole-body minus head) body composition, including fat-free soft tissue mass (FFSTM), fat mass, and BMD were measured using dual energy X-ray absorptiometry (Scotland: iDXA; GE Encore, version 13.40.038, GE Healthcare, Madison, WI, USA; South Africa: DXA; Discovery-W®, version 12.7.3.7, Hologic, Bedford, MA, USA) according to standard procedures. Appendicular skeletal muscle mass (ASM), the sum of FFSTM (kg) of both legs and arms, was adjusted for BMI (ASM_{BMI}). BMD was quantified using DXA at the lumbar spine (lumbar vertebrae L1-L4), total hip, and femoral neck.

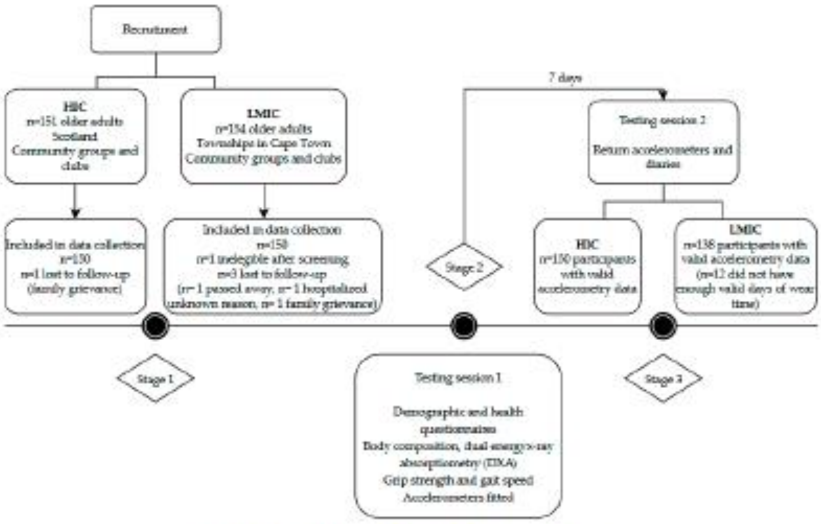


Figure 1. Recruitment and study design details.

2.3. *Sarcopenia and Bone Mineral Density Cut Points*

To assess sarcopenia components, we considered grip strength adjusted for BMI (grip $strength_{BMI}$) as our measure of muscle strength, and ASM adjusted for BMI (ASM_{BMI}) as our measure of muscle mass, as used by the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project [33]. Recommendations for cut points for weakness and low muscle mass included grip $strength_{BMI}$ of <0.1 for men and <0.56 for women, and ASM_{BMI} of <0.789 for men and <0.512 for women, respectively [33]. Participants presenting with both weakness and low muscle mass were classified as sarcopenic. The recommended cut point for gait speed is $\leq 0.8\ m{\cdot}s^{-1}$ [33].

The International Society for Clinical Densitometry (ISCD) guidelines for adults aged ≥ 50 years were used to determine those with osteopenia (t-score -2.5 to -1) and osteoporosis (t-score < -2.5) at 1 or more bone sites [34,35].

2.4. *Hand Grip Strength and Functional Fitness Tests*

Grip strength (kg) was measured with a hand dynamometer (Scotland: T.K.K.5001, Grip-A, Takei, Tokyo, Japan; South Africa: T.K.K. 5401, Grip-D, Takei, Tokyo, Japan). Measures were taken on the non-dominant side, while the participants were in a seated position with their elbow by the side at 90° angle position. The test was repeated 3 times with a 1-min rest between each effort. The maximum score achieved was used in the analysis [36].

Gait speed was assessed via a 6-m walk test. The participants were instructed to walk at a fast pace between two markers set 10 m apart. Time was measured manually for a 6 m distance (from 2 m to 8 m) to avoid influences of acceleration and deceleration. The mean score ($m{\cdot}s^{-1}$) from 3 measurements was recorded [37].

2.5. *Movement Behaviors*

Movement behaviors (MVPA, LPA, SB, sleep) were measured using ActiGraph GT3X+ (ActiGraph, Pensacola, FL, USA) accelerometer for 7 consecutive days. The device was worn over the right hip with an elastic belt [38] and initialized to collect data at 80 Hz. On the day of the trial, a trained researcher provided verbal, visual, and written instructions on how to wear the monitor correctly and checked participant self-attachment. Participants wore the monitor 24 h/day removing only for water-based activities (as bathing, swimming, or showering). Participants were asked to complete a written log to indicate times when the device was not worn. A second log was used to collect information on sleep behavior including time going to sleep and waking up. Activity counts were measured in 60-s epochs, and data were processed using ActiLife 6 software (ActiGraph Inc, Pensacola, FL, USA).

2.6. Accelerometry Data Management

Periods of nocturnal sleep were identified by visual inspection of ActiLife software outcomes [39]. Sleep diaries were used to check participant reported sleep times where nocturnal sleep periods were difficult to identify. Nocturnal time in bed (TiB, minutes) was used as the primary measure of sleep and it was used for analysis. To be included in the analysis, a participant needed to have at least 3 valid sleep nights (defined as >160 min of sleep time). Following the identification of nocturnal sleep periods, the remaining accelerometry wear time was checked for the other movement behaviors (PA and SB). A valid PA and SB dataset comprised of at least 4 days of valid wear time (with at least 1 weekend day). A single valid day was defined as a day with 600 min of wear time, following the exclusion of any other non-wear periods (non-wear time was defined as 60 min of consecutive zeros with allowance for 2 minutes of activity counts between 0 and 100). SB, LPA, and MVPA were classified using established cut-offs, as previously used in NHANES: sedentary < 100 cpm, total PA ≥ 100 cpm, $100 <$ LPA < 2020, MVPA ≥ 2020 cpm [40]. The duration of time spent in each activity behavior was determined (mins/day), and all behaviors accounted for whole participant daily time (1440 min).

2.7. Sleep and Physical Activity Recommendations

To assess sleep patterns, we classified participants according to National Sleep Foundation (NSF) recommendations [41]. Participants were considered as meeting sleeping recommendations if they accumulated 7–9 h of sleep per night, while older adults were considered to meet recommendations if their nocturnal sleep was between 7 and 8 h. Adults sleeping less than 6 h and older adults sleeping less than 5 h were considered as sleeping too little, while participants were sleeping too much if they accumulated more than 10 h of sleep for adults and more than 9 h of sleep for older adults.

Participants were classified as meeting PA guidelines according to the most recent WHO guidelines [16] on aerobic PA (do at least 150–300 min of moderate-intensity aerobic PA; or at least 75–150 min of vigorous-intensity aerobic PA; or an equivalent combination of MVPA, throughout the week).

2.8. Sleep Quality

The Pittsburgh Sleep Quality Index (PSQI) was used to evaluate sleep quality. The PSQI has been previously validated in high- [42] and low-income settings [43]. It consists of 19 self-rated items referring to the previous 4 weeks. This questionnaire provides a total score (>5 indicates poor sleep quality) along with seven sub-components: habitual sleep efficiency, subjective sleep quality, sleep disturbances, use of medication, daytime dysfunction, and sleep latency. Each of the 7 components have a range of 0–3 points where "0" indicates no difficulty and "3" indicates severe difficulty. Cronbach's alpha internal consistency for this questionnaire in the Scottish sample was 0.75, while in the South African cohort was 0.71.

2.9. Statistical Methods

Analysis was conducted using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY, USA), and compositional analyses were conducted using the open-source software Physical Activity CoDa Regression Model (PACRM) [44].

Traditional descriptive statistics were stratified according to Scottish and South African groups. The normality of the data was analyzed by the Kolmogorov–Smirnov test combined with Q-Q plots. Regression assumptions were checked, and in all models, non-normally distributed dependent variables were transformed with the most appropriate transformation. Descriptive statistics for continuous variables were expressed as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Categorical variables were expressed as frequency and percentage. PA variables were presented as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate in Table 1. For compositional data analysis, compositional means of movement behaviors were considered (Table S1). χ^2 (chi-squared) or Fisher's exact test (where appropriate) was conducted to determine differences in sleep sub-components of the PSQI (Table S2).

Table 1. Descriptive characteristics of Scottish and South African cohorts.

Variables	Scottish Cohort (n = 150)	South African Cohort (n = 138)	*p*-Value
Age (years)	69 (66–73)	68 (64–71)	0.085
Sex (n, %), Females	117 (78)	113 (82)	0.463
Education (n, %)			**<0.001**
Less than secondary	13 (9)	72 (52)	
Completed secondary			
Completed tertiary	27 (18)	65 (47)	
Housing density			
	110 (72)	1 (1)	
	0.3 (0.2–0.3)	1 (0.6–1.4)	**<0.001**
Smoking status (n, %)			0.283
Never smoked	94 (63)	100 (73)	
Previous smoker	53 (35)	22 (16)	
Current smoker	3 (2)	16 (12)	
Car owner (n, %)	141 (94)	17 (12)	**<0.001**
Civil status (n, %)			0.228
Single	30 (20)	55 (40)	
Married or living with a partner	105 (70)	25 (18)	
Widowed			
	15 (10)	58 (42)	
Employed, yes (n, %)	3 (2)	0	0.095
Accelerometer total wear time (min/day)	913 ± 46	878 ± 80	**<0.001**
Total PA (min/week)	324 ± 64	334 ± 96	0.112
SB (min/day)	593 (546–638)	539 (491–587)	**<0.001**
LPA (min/day)	287 ± 55	318 ± 92	**0.001**
MVPA (min/day)	27 (15–44)	11 (3–21)	**<0.001**
Nocturnal TiB (min/night)	513 ± 45	555 ± 75	**<0.001**
SB (% daily wear time)	41 (38–44)	37 (34–41)	**<0.001**
LPA (% daily wear time)	20 ± 4	22 ± 6	**0.001**
MVPA (% daily wear time)	2 (1–3)	1 (0.2–2)	**<0.001**
Nocturnal TiB (% daily wear time)	36 ± 3	39 ± 5	**<0.001**
MVPA (min/week)	153 (88–265)	64 (18–128)	**<0.001**
Meeting PA guidelines ≥150 min/week (n, %)	77 (51)	28 (20)	**<0.001**
Meeting sleep recommendations (n, %)	41 (27)	32 (23)	0.498
Sleeping within the appropriate range (n, %)	76 (51)	36 (26)	**<0.001**
Sleeping too short (n, %)	0	6 (4)	**0.011**
Sleeping too long (n, %)	33 (22)	64 (45)	**<0.001**

All normally distributed and skewed data are reported as mean ± SD and median (IQR, 25–75th percentile), respectively. Movement behaviors data are reported as traditional mean or median (min/day) and %. Abbreviations: HIV, human immunodeficiency virus. PA, physical activity. SB, sedentary behavior. LPA, light physical activity. MVPA, moderate-to-vigorous physical activity. TiB, time-in-bed. *p*-values represent a significant difference between groups. Parametric and non-parametric (Mann–Whitney *U*, Kruskal–Wallis) independent *t*-tests were conducted on normally distributed and skewed data, respectively. Chi-squared test was used to determine differences in frequency of each variable between Scottish and South African cohorts. Statistically significant results ($p < 0.05$) are highlighted in bold.

A compositional multivariate analysis of variance (MANOVA) on isometric transformed data was used to determine differences in time use composition between Scottish and South African participants (independent variable) [45]. To interpret differences between movement behaviors, we developed bootstrap percentile 95% confidence intervals [45]. Prior to MANOVA calculations, assumptions for this test were checked, and as they were not violated, we firstly calculated unadjusted MANOVA model and later considered covariates on the basis of previous literature [46]. Covariates in the model included: age, sex, BMI, education, and smoking status, as well as human immunodeficiency virus (HIV) and diabetes presence in the South African sample.

To investigate the associations between proportions of time spent in the movement behaviors and musculoskeletal outcomes, we then computed linear regression models separately for both cohorts. For each cohort, 4 compositional linear regression models were performed for each sarcopenia component (grip strength$_{BMI}$, ASM$_{BMI}$, and gait speed) and BMD site (femoral neck BMD, total hip BMD, and lumbar spine BMD) as response via isometric log-ratio (ilr) transformation of the time-use composition (explanatory variables) along with covariates. First, the composition of time spent in sleep, SB, LPA, and MVPA was considered. A set of 3 ilr-coordinates was obtained via sequential binary partition. Model p-values and R^2 coefficients were calculated from unadjusted linear regression models to assess the presence of a statistically significant relationship between time use composition and musculoskeletal components. The first coefficient (γ) and the corresponding p-value for each of the 4 linear regressions were used to determine if the time spent in a specific behavior relative to the others was significantly associated with grip strength$_{BMI}$, ASM$_{BMI}$, gait speed, and BMD. We further adjusted BMD models for sarcopenia components due to the crosstalk between these environments [14]. Outcomes from CoDa analysis should not be interpreted in isolation due to their nature (ratios between behaviors); regression coefficients should be considered relative to the remaining behaviors. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Participant Characteristics

Age and sex did not differ between the South African and Scottish cohorts. However, compared to the Scottish cohort, South African participants reported a lower socioeconomic status, which was reflected in a higher housing density, lower level of education, and lower car ownership (Table 1). Smoking behavior and civil and employment status did not differ between the two cohorts. In the South African group, 22.5% of participants had diabetes and 8.7% were living with HIV.

Scottish and South African older adults accumulated similar amounts of total PA over the 7 days and showed significant differences between groups across all movement behaviors (Table 1 and Table S1) and 24-h time-use composition (Figure 2). The geometrics means, used for the 24-h time-use composition analysis, are shown in Table S1. In particular, Scottish participants spent more time in MVPA and SB compared to their South African counterparts. Alternatively, South African older adults spent more time in LPA and had longer nocturnal sleep duration. According to the most recent WHO recommendations for PA, the threshold of 150 min of combined MVPA was achieved by 51.4% of the Scottish cohort and 20.3% of the South African cohort. Among individuals meeting WHO PA recommendations, 18.7% of the Scottish and 6.5% of the South African older adults completed 300 min or more of MVPA during the week.

No significant differences were found in the number of people meeting NSF sleep recommendations in the two cohorts (Table 1). However, a higher percentage of Scottish older adults had an appropriate number of sleeping hours (50.7% vs. 25.5%, $p < 0.001$), while a greater percentage of South African participants were sleeping too long (45.4% vs. 22.0%, $p < 0.001$). Alongside longer nocturnal sleep, the South African cohort reported a greater number of sleep disturbances and daytime dysfunction, higher use of sleeping medication, and worse sleep latency, but greater sleep efficiency than the Scottish older adults (Table S2). However, no differences in the overall PSQI score were found between cohorts.

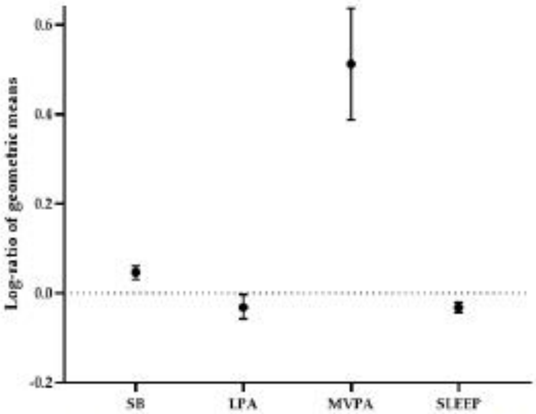


Figure 2. Log-ratio (95% confidence intervals) difference between the Scottish and South African groups for each movement behavior. Lines falling above the dotted line indicate that relative time spent in the specific behavior was higher in the Scottish cohort compared to South African cohort. Conversely, lines falling below the dotted line indicate that the component was higher in the South African sample.

3.2. Body Composition, Bone Mineral Density, and Functional Measures

Body composition differed between the two cohorts (Table 2), with South African older adults having higher fat mass (kg and %) and BMI, and Scottish participants having higher FFSTM and ASM_{BMI}. However, unadjusted ASM did not differ between cohorts. Significant differences were found in functional outcomes, with Scottish older adults displaying higher grip strength and grip $strength_{BMI}$ and South Africans having a faster gait speed. According to the BMI adjusted FNIH cut-off, the South African group had a higher prevalence of sarcopenia than the Scottish cohort (30.4% vs. 2.0%, $p < 0.001$). Higher rates of osteopenia were found in the Scottish cohort, while higher rates of osteoporosis were found in the South African cohort (Table 2).

Table 2. Body composition, and functional and musculoskeletal variables of Scottish and South African cohorts.

Variables	Scottish Cohort (n = 150)	South African Cohort (n = 138)	*p* Value
	Body composition		
Height (cm)	164.7 ± 9.2	157.3 ± 7.2	<0.001
Body mass (kg)	69.0 (60.8–77.3)	79.3 (66.8–93.2)	<0.001
BMI (kg/m^2)	25.7 (23.5–28.3)	31.7 (27.8–38.3)	<0.001
Underweight (n, %)	2 (1.4)	1 (0.7)	
Normal (n, %)	57 (38.0)	21 (15.2)	
Overweight (n, %)	69 (46.0)	32 (23.2)	
Obese (n, %)	22 (14.6)	84 (60.9)	
Fat mass (kg)	25.4 ± 8.9	34.8 ± 14.1	<0.001
Fat mass (%)	37.5 (31.6–41.3)	47.2 (40.7–51.8)	<0.001
FFSTM (kg)	40.1 (36.3–45.2)	37.2 (33.4–42.3)	<0.001
ASM (kg)	17.6 (19.5–27.5)	17.3 (15–20.4)	0.066
ASM_{BMI} (kg/m^2)	0.7 (0.6–0.8)	0.5 (0.5–0.6)	<0.001
Sarcopenia (n, %)	3 (2.0)	42 (30.4)	<0.001

Table 2. *Cont.*

Variables	Scottish Cohort (n = 150)	South African Cohort (n = 138)	*p* Value
Functional and sarcopenia measures			
Grip strength (kg)	23.0 (19.5–27.5)	20.1 (17.0–23.8)	**<0.001**
Grip strength (kg) men	34.7 (30.0–39.5)	23.8 (19.8–29.0)	**<0.001**
Grip strength (kg) women	21.7 (18.5–24.8)	19.6 (16.8–22.9)	**0.001**
Grip strength$_{BMI}$ (kg/m^2)	0.9 (0.7–1.2)	0.6 (0.5–0.8)	**<0.001**
Grip strength$_{BMI}$ (kg/m^2) men	1.3 (1.2–1.5)	1.0 (0.8–1.2)	**<0.001**
Grip strength$_{BMI}$ (kg/m^2) women	0.9 (0.7–1.0)	0.6 (0.5–0.7)	**<0.001**
Gait speed (m/s)	1.5 (1.4–1.7)	1.6 (1.4–1.7)	**0.041**
Bone mineral density			
Femoral neck BMD (g/cm^2)	0.854 ± 0.149	0.758 ± 0.161	
Total hip BMD (g/cm^2)	0.905 ± 0.150	0.896 ± 0.177	
Lumbar spine BMD (g/cm^2)	1.112 ± 0.208	0.940 ± 0.191	
Femoral neck BMD$_{HEIGHT}$ (g/cm^2)	0.515	0.482	
Total hip BMD$_{HEIGHT}$ (g/cm^2)	0.547	0.569	
Lumbar spine BMD$_{HEIGHT}$ (g/cm^2)	0.672	0.598	
Femoral neck T score	−1.3 (−1.7–0.6)	−0.8 (−1.8–0.1)	
Total hip T score	−1.1 (−1.7–−0.4)	−0.3 (−1.3–0.7)	
Lumbar spine T score	−0.1 (−0.9–−0.7)	−1.1 (−2.2–0.1)	
Osteopenia (n, %)	105 (70.0)	54 (39.1)	
Osteoporosis (n, %)	16 (10.7)	28 (20.3)	

All normally distributed and skewed data are reported as mean ± SD and median (IQR—25-75th percentile), respectively. Abbreviations: BMI, body mass index. FFSTM, fat-free soft tissue mass. ASM, appendicular skeletal muscle mass. ASMBMI, appendicular skeletal muscle mass adjusted for body mass index. Grip strength$_{BMI}$, grip strength adjusted for body mass index. BMD, bone mineral density. *p*-values represent a significant difference between groups. Parametric and non-parametric (Mann–Whitney *U*) independent *t*-tests were conducted on normally distributed and skewed data, respectively. Chi-squared test was used to determine differences in frequency of each variable between Scottish and South African cohorts. Statistically significant results ($p < 0.05$) are highlighted in bold.

3.3. Relationship between 24-h Time Use Composition and Musculoskeletal Health in South African and Scottish Older Adults

Compositional linear regression models in relation to sarcopenia components and BMD are shown in Table 3. In the South African cohort, more time spent in MVPA relative to the other behaviors was associated with higher gait speed and total hip BMD. When adjusting for grip strength, ASM, and/or gait speed, we found that MVPA remained positively associated with total hip BMD in the South African cohort (Table 4). Therefore, the relationship between relative time spent in MVPA and total hip BMD was independent of sarcopenia components. When additionally adjusting the model for grip strength and ASM (Table 4), we found a positive association between relative time in MVPA and femoral neck BMD; however, when gait speed was included as a covariate, the positive association with femoral neck BMD was no longer significant.

Table 3. Compositional linear regression for the associations between movement behaviors and musculoskeletal outcomes.

Variables	γ Sleep	*p* Value	γ SB	*p*-Value	γ LPA	*p*-Value	γ MVPA	*p*-Value	Model R^2	Model *p*-Value
South African cohort										
Grip strength$_{BMI}$ (kg/m^2)	0.114	0.310	−0.147	0.123	0.020	0.745	0.013	0.435	**0.110**	**0.001**
ASM$_{BMI}$ (kg/m^2)	0.036	0.571	−0.057	0.289	0.019	0.582	0.002	0.856	**0.200**	**<0.001**
Log gait speed (m/s)	−0.035	0.399	−0.010	0.768	0.019	0.380	**0.026**	**<0.001**	**0.349**	**<0.001**
Femoral neck BMD (g/cm^2)	−0.064	0.415	0.023	0.725	0.021	0.612	0.020	0.087	**0.070**	**0.021**
Total hip BMD (g/cm^2)	−0.020	0.807	−0.012	0.863	0.001	0.974	**0.031**	**0.011**	**0.099**	**0.003**
Lumbar spine BMD (g/cm^2)	−0.014	0.894	−0.037	0.664	0.066	0.220	−0.015	0.296	0.008	0.787

Table 3. *Cont.*

Variables	γ Sleep	p Value	γ SB	p-Value	γ LPA	p-Value	γ MVPA	p-Value	Model R^2	Model p-Value
					Scottish cohort					
Grip $strength_{BMI}$ (kg/m^2)	0.065	0.688	−0.116	0.377	−0.045	0.644	**0.097**	**0.001**	**0.122**	**<0.001**
ASM_{BMI} (kg/m^2)	−0.039	0.589	−0.022	0.706	0.012	0.789	**0.049**	**<0.001**	**0.119**	**<0.001**
Gait speed (m/s)	0.100	0.450	−0.090	0.378	−0.012	0.876	0.007	0.773	0.049	0.063
Log femoral neck BMD (g/cm^2)	0.132	0.071	−0.116	0.051	−0.038	0.393	0.022	0.105	**0.067**	**0.018**
Log hip total BMD (g/cm^2)	−0.019	0.698	−0.029	0.458	0.044	0.131	0.004	0.696	0.013	0.583
Log spine BMD (g/cm^2)	−0.043	0.438	0.030	0.503	0.025	0.445	−0.013	0.208	0.013	0.591

Compositional regression coefficients (γ) for each movement behavior represent the association for time spent in each behavior relative to all other behaviors. Model p-value and R^2 are based on the unadjusted model. Regression coefficients and corresponding p-values were adjusted for age, sex, education, and smoking status. Gait speed and bone mineral density (BMD) variables were further adjusted for body mass index (BMI). Regression coefficients and corresponding p-values for South African sample were additionally adjusted for diabetes and human immunodeficiency virus (HIV) prevalence. Statistically significant associations ($p < 0.05$) are highlighted in bold.

Table 4. Compositional linear regression model for South African cohort between bone mineral density variables and movement behaviors considering bone-muscle crosstalk.

Variables	γ Sleep	p Value	γ SB	p-Value	γ LPA	p-Value	γ MVPA	p-Value
			Model 1: additionally adjusted for grip strength					
Femoral neck BMD (g/cm^2)	−0.080	0.257	0.019	0.748	0.039	0.326	**0.022**	**0.043**
Hip total BMD (g/cm^2)	−0.048	0.512	0.002	0.984	0.015	0.724	**0.032**	**0.005**
Spine BMD (g/cm^2)	−0.025	0.778	−0.029	0.707	0.064	0.205	−0.010	0.442
			Model 2: additionally adjusted for ASM					
Femoral neck BMD (g/cm^2)	−0.087	0.236	0.014	0.814	0.049	0.230	**0.024**	**0.029**
Hip total BMD (g/cm^2)	−0.049	0.525	−0.002	0.980	0.015	0.720	**0.035**	**0.002**
Spine BMD (g/cm^2)	−0.036	0.709	−0.038	0.629	0.081	0.125	−0.008	0.565
			Model 3: additionally adjusted for gait speed					
Femoral neck BMD (g/cm^2)	−0.078	0.277	0.014	0.815	0.042	0.292	0.021	0.064
Hip total BMD (g/cm^2)	−0.039	0.596	−0.005	0.933	0.005	0.707	**0.029**	**0.017**
Spine BMD (g/cm^2)	−0.022	0.815	−0.038	0.627	0.070	0.176	−0.011	0.464
			Model 4: additionally adjusted for grip strength + ASM + gait speed					
Femoral neck BMD (g/cm^2)	−0.086	0.244	0.021	0.725	0.043	0.301	0.022	0.056
Hip total BMD (g/cm^2)	−0.041	0.590	0.007	0.913	0.004	0.922	**0.030**	**0.013**
Spine BMD (g/cm^2)	−0.039	0.497	−0.026	0.740	0.070	0.190	−0.011	0.452

Compositional regression coefficients (γ) for each movement behavior represent the association for time spent in each behavior relative to all other behaviors. Regression coefficients and corresponding p-values were adjusted for age, gender, education, smoking status, body mass index (BMI), diabetes, and human immunodeficiency virus (HIV) prevalence. Models 1, 2, and 3 were respectively additionally adjusted for grip strength, appendicular skeletal muscle mass, and gait speed. Model 4 was additionally adjusted for all sarcopenia components. Statistically significant associations ($p < 0.05$) are highlighted in bold.

In contrast, the Scottish cohort showed that higher relative time spent in MVPA was positively associated with higher grip $strength_{BMI}$ and ASM_{BMI} (Table 3). No associations between specific movement behaviors and BMD were found. When adjusting the model for grip strength, ASM, and/or gait speed (Table 5), we did not find any association between 24-h time use composition and BMD outcomes. However, when adjusting for only grip strength, we found that the relative time spent in SB was negatively associated with femoral neck BMD.

Table 5. Compositional linear regression model for Scottish cohort between bone mineral density variables and movement behaviors considering bone-muscle crosstalk.

Variables	γ Sleep	p-Value	γ SB	p-Value	γ LPA	p-Value	γ MVPA	p-Value
Model 1: additionally adjusted for grip strength								
Log femoral neck BMD (g/cm^2)	0.113	0.056	−0.113	0.044	−0.045	0.287	0.025	0.067
Log hip total BMD (g/cm^2)	−0.030	0.519	−0.019	0.602	0.042	0.137	0.007	0.430
Log spine BMD (g/cm^2)	−0.038	0.485	0.033	0.449	0.017	0.603	−0.012	0.237
Model 2: additionally adjusted for ASM								
Log femoral neck BMD (g/cm^2)	0.133	0.056	−0.108	0.053	−0.046	0.275	0.022	0.108
Log hip total BMD (g/cm^2)	−0.030	0.512	−0.017	0.656	0.042	0.141	0.005	0.573
Log spine BMD (g/cm^2)	−0.038	0.486	0.033	0.454	0.017	0.603	−0.012	0.250
Model 3: additionally adjusted for gait speed								
Log femoral neck BMD(g/cm^2)	0.130	0.061	−0.109	0.051	−0.044	0.295	0.023	0.085
Log hip total BMD (g/cm^2)	−0.031	0.509	−0.018	0.620	0.043	0.131	0.006	0.481
Log spine BMD (g/cm^2)	−0.007	0.492	0.033	0.461	0.017	0.606	−0.002	0.247
Model 4: additionally adjusted for grip strength + ASM + gait speed								
Log femoral neck BMD (g/cm^2)	0.134	0.054	−0.008	0.053	−0.009	0.252	0.023	0.094
Log hip total BMD (g/cm^2)	−0.028	0.546	−0.018	0.635	0.040	0.162	0.006	0.519
Log spine BMD (g/cm^2)	−0.376	0.490	0.032	0.461	0.018	0.601	−0.012	0.251

Compositional regression coefficients (γ) for each movement behavior represent the association for time spent in each behavior relative to all other behaviors. Regression coefficients and corresponding p-values were adjusted for age, gender, education, smoking status, and body mass index (BMI). Models 1, 2, and 3 were respectively additionally adjusted for grip strength, appendicular skeletal muscle mass, and gait speed. Model 4 was additionally adjusted for all sarcopenia components. Statistically significant associations ($p < 0.05$) are highlighted in bold.

In both cohorts, the overall 24-h time use composition accounted for a similar proportion of the variance for grip strength and ASM (Table 3). Conversely, in the South African cohort only, a significant association between movement behaviors and gait speed was reported. Time use composition explained almost 35% of the variance in gait speed in this cohort, with MVPA significantly dictating the association. The overall 24-h composition explained a similar amount of variance for femoral neck BMD in both cohorts (±7%). However, an association between overall 24-h composition and hip total BMD was only reported the South African cohort and accounted for ±10% of the variance.

4. Discussion

In the current study, we assessed and compared movement behaviors of older adults from low-income South African and high-income Scottish communities and examined associations with various measures of musculoskeletal health. Although the total amount of weekly PA between the two cohorts was similar, there were differences in the relative time spent in all behaviors, with Scottish participants spending more time in SB and MVPA and South African older adults spending more time in LPA and nocturnal sleep. We found a positive association between relative time in MVPA and sarcopenia components and BMD, but these differed between the cohorts. Specifically, higher MVPA time relative to the other behaviors was associated with higher ASM_{BMI} and grip $strength_{BMI}$ in the Scottish cohort, and higher gait speed and total hip BMD in the South African cohort. Our results suggest that interventions targeted at older adults should consider the importance of engaging in higher intensities of PA patterns irrespective of the sociodemographic profile. However, the relationships between MVPA and components of musculoskeletal health were different between cohorts.

The first important finding was that the representative samples of older adults from the high-income and the low-income countries had significantly different time allocation in 24-h movement behaviors. Specifically, Scottish older adults displayed higher relative time in MVPA compared to the South African counterpart. This finding agrees with previous evidence highlighting high engagement in MVPA in high-income settings [17].

Conversely, we reported low time spent in MVPA relative to the other behaviors in the South African sample, a common issue of LMICs [21]. This finding could be explained by the fact that most of the participants involved in our study were either unemployed or retired. The main contributor to engagement in MVPA in LMICs is the occupational domain and to lesser extent participation in leisure activities [47,48]. In agreement with previous studies [49], South African older adults spent more time in LPA relative to the other movement behaviors. Thus, the understanding of population's socioeconomic context is fundamental to translate evidence into appropriate policies and interventions.

Our finding of a beneficial association between MVPA and sarcopenia components confirms the importance of PA intensity on muscle mass, muscle strength, and physical performance. Our observations agree with recent studies involving older adults from Swedish and Tasmanian cohorts [46,50]. However, the novelty of our findings is in the consideration of the time spent across the entire 24-h day, while previous studies considered different movement behaviors in isolation. Regular weekly MVPA has been found to reduce sarcopenia risk and to be consistently associated with reduced incidence of these components [46]. Additionally, a previous study highlights a reduction in sarcopenia prevalence by displacing 15 min of either SB or LPA in favor of MVPA in older adults [10]. However, this study did not consider the effect of the whole 24-h spectrum on movement behaviors.

While in the Scottish cohort, MVPA was positively associated with both ASM_{BMI} and grip $strength_{BMI}$, in the South African cohort, the relative time spent in MVPA was positively associated with gait speed. Although the muscular outcomes positively associated with MVPA are different between the cohorts, the findings overall suggest a protective role of higher PA intensities on functional outcomes. Differences in functional outcomes between the two cohorts could be due to differences in modalities and activities to achieve higher PA intensities. Scottish older adults engage in MVPA mostly for recreational and exercise purposes with gym-based exercise and sports (involving also upper body usage) [21], potentially resulting in greater values of grip strength and muscle mass. In contrast, the main contributors to PA in the South African cohort are active travel and occupational duties [22], leading to greater engagement of lower body functionality. Consequently, our results confirm the importance of MVPA for muscular health in older adults when considered relative to other movement behaviors. However, the influence of PA domains (leisure and occupational) among groups of older adults in different socio-economic settings should be considered.

The present study shows associations between movement behaviors and hip BMD in the South African cohort. Our results agree with previous studies reporting greater hip and femoral neck BMD with the engagement in habitual PA and MVPA [51]. The reason for the beneficial effect of PA on hip BMD could be related to greater cortical bone in femoral neck and total hip components, which is more susceptible to mechanical loading and absorption of ground reaction forces [52,53]. Alternatively, the density of bones at the lumbar spine, due to the predominance of trabecular bone, is more sensitive to the metabolic milieu rather than mechanical loading [54]. Total hip BMD was positively associated with relative time in MVPA in the South African cohort, but not in the Scottish cohort. Most of the PA performed in the South African group is low intensity walking for transport [48], leading to a greater influence and protective effect of PA on hip bones. Additionally, when adjusting our models for sarcopenia components in the South African cohort, the association between MVPA and total hip BMD remained significant, highlighting the independence of this relationship from muscular and functional factors. Despite this association, in our study, the prevalence of osteoporosis was still high in the South African cohort. This could be explained by the large proportion of South African older adults not meeting PA guidelines, which can lead to a decline in bone integrity; however, other risk factors for osteoporosis, such as nutrition, should be acknowledged. Thus, the importance of meeting PA recommendations should be reinforced in older adults from LMICs. However, the ideal amount of MVPA to prevent a decline in BMD is still poorly defined as the dose–response association between MVPA and BMD is not fully understood [55]. Indeed, multiple exercise types (involving balance, endurance, resistance, and functional exercise) appear to be more effective for maintaining bone health and reducing the risk of fracture [56]. Future longitudinal and intervention studies are required to address this research gap.

Previous data have shown that time spent sitting is negatively associated with hip BMD [57], and we have shown that the association between SB and femoral neck BMD was mediated by grip strength in Scottish older adults. Grip strength is well recognized as a proxy for physical activity [58] and is consistently associated with BMD across sites [59,60]. Additionally, grip strength was also a significant contributor to the model, further supporting the idea that the association between BMD and SB is mediated by muscle strength. This finding reinforces the idea of the crosstalk between muscle and bone, suggesting a shared pathological process in older adults [14,61]. Previous studies reported the negative impact of SB, independently of PA, on bone integrity [62]. Interestingly, when considering the whole 24 h spectrum in the Scottish cohort, SB was the only behavior associated with BMD and this was only observed after adjusting for grip strength. Conversely, higher relative daily time spent in MVPA was associated with better hip total bone health outcomes in the South African cohort. However, when muscle mass and muscle strength were considered in the model, femoral neck BMD was also positively associated with relative time spent in MVPA. This association further reinforces the presence of a muscle-bone unit, suggesting that future interventions should target engagement in resistance training [63] involving also upper body activities in older adults in both HIC and LMIC.

Our data suggest that MVPA was associated with better musculoskeletal health in both cohorts; however, this poses a challenge as a low percentage of South African older adults met PA guidelines as indicated by their lower engagement in higher PA intensities or MVPA. A previous study [64] showed that barriers to MVPA in a low-income South African setting included the perception of poor facilities and safety issues in the neighborhood, making it harder to engage in recreational MVPA. Inequalities in accessing opportunities to engage in leisure PA occur in most LMICs, with poor and overcrowded environments, lack of adequate facilities, and safety representing major barriers to PA [65]. Thus, when targeting engagement in PA in LMICs, we need to acknowledge the associated challenges, with the potential aim of removing these barriers. Conversely, a large number of Scottish older adults were already engaging in appropriate amount of PA. However, they also spent ≈10 h of the day in SB, and in line with the most recent recommendations by the WHO, this may have detrimental effects on increased risk of developing a chronic disease and mortality [66]. To sustain beneficial effects that PA has on different health outcomes with ageing, we should support older adults to maintain PA levels while reducing SB, particularly during the COVID-19 pandemic.

Along with differences in PA, we also found differences in the relative time spent sleeping. A recent review suggested that shorter and longer sleepers are at greater risk of developing muscle failure and lower values of BMD, when considering sleep in isolation [67,68]. Conversely, when the whole 24 h day was considered, no relationship between sleep duration and musculoskeletal health was found. Furthermore, in line with previous findings [23], the South African cohort in the present study had longer sleeping duration when compared to the Scottish cohort. Analysis of the PSQI subcomponents showed that the South African participants reported more sleep disturbances, longer sleep latency, higher use of medication, and more daytime dysfunction. These results could be related to the higher housing density in the South African group (three times more than the number of people per room in Scotland). Indeed, previous studies have shown that 42% of the people living in South African townships indicated that between 5 and 10 people were living in the housing unit allotted to them [69], and specifically 81.1% were sharing sleeping space or bedroom [70]. Poor sleep quality and age-related changes in sleep patterns have been shown to have adverse effects on health during ageing, particularly on mental and physical health [71]. Therefore, attention should be given to sleep quality and appropriate sleep duration when investigating ageing, and further work on this topic is warranted.

Strengths and Limitations

This study has several strengths, including the use of objectively measured movement behavior outcomes in both high- and low-income communities with a shared protocol. With CoDa, we considered the whole 24-h time use composition, allowing us to investigate the combined effect of movement behaviors on musculoskeletal outcomes. However, different machines were used for multiple measures (whole body composition, bone measures, and grip strength), which meant that a direct comparison across these measures was not feasible. Regardless, this does not preclude the comparison of associations between movement behaviors and musculoskeletal outcomes. Due to ethics requirements, older adults with diabetes were not included in the Scottish cohort. Consequently, our findings cannot be generalized to all HIC older adult population. However, we performed a sensitivity analysis excluding participants with diabetes and HIV in the South African cohort. The results obtained for group differences in 24-h movement behaviors and associations with musculoskeletal outcomes did not change (data not shown). The study is limited by its cross-sectional design, precluding any claims on causal inference from our results. Thus, findings from this study can identify potential future targets that need to be addressed in future intervention or longitudinal studies. Additionally, the current study did not collect data on cognitive functioning or impairments. Future studies should include cognitive screening, especially if including participants at risk. The participants included in this study were living independently and therefore it is less likely that cognitive impairment would have an impact on the results presented. Lastly, we did not take into account the role of habitual strength training, as we focused on aerobic physical activity and future studies should also consider the potential mode specific training effects on musculoskeletal determinants.

5. Conclusions

We highlight the importance of the relative time spent in MVPA across the whole day on musculoskeletal health in older adults in both LMIC and HIC. Higher daily time allocations to MVPA relative to other behaviors were associated with better musculoskeletal and bone health. While the beneficial effect of MVPA in isolation on muscle and bone integrity is already known, recent evidence argued whether this positive impact remained when the whole day is considered. Our findings confirm the protective role of MVPA on muscle mass, muscle strength, physical functioning, and BMD. Specifically, in the high-income Scottish group, higher time spent in MVPA relative to the other behaviors was associated with greater muscle mass and muscle strength, while relative time spent in SB, mediated by muscle strength, was the main contributor to lower BMD. Thus, national plans and policymakers should support older adults in HIC in maintaining appropriate volume and intensity of PA and reducing SB with ageing. Conversely, in the low-income South African setting, higher relative time in MVPA had a positive effect on physical functioning and BMD. However, the presence of barriers to PA in LMICs should be acknowledged with a focus on PA security, ensuring equality in the access to sufficient, safe, and enjoyable spaces for PA. Thus, an integrated approach including the promotion of high-intensity PA and equality in PA access is needed.

Accordingly, future interventions should target the knowledge around the importance of engaging in higher PA intensities with ageing for musculoskeletal health acknowledging the challenges in different socio-economic settings.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ijerph18084310/s1, Table S1: Movement behaviors MANOVA between Scottish and South African cohorts. Table S2: Pittsburgh Sleep Quality Index sub-components results for Scottish and South African cohorts.

Author Contributions: Conceptualization and design, I.P., J.H.G., A.M.H., A.E.M.; performed Experiments, I.P., A.E.M.; analyzed data, I.P., A.E.M., S.A.T.; interpreted results,; I.P., J.H.G., A.M.H., A.E.M., S.A.T., L.K.M., N.E.B., I.J.G., R.C., P.D.; writing—original draft preparation, I.P, A.E.M.; writing—review and editing, I.P., J.H.G., A.M.H., A.E.M., S.A.T., L.K.M., N.E.B., I.J.G., R.C., P.D.; approved final version of manuscript, I.P., J.H.G., A.M.H., A.E.M., S.A.T., L.K.M., N.E.B., I.J.G., R.C., P.D. All authors have read and agreed to the published version of the manuscript.

Funding: Running costs for the South African study was funded by the Medical Research Council Confidence in Global Nutrition and Health Research (no. MR/R020221/1). The APC was funded by the University of Stirling.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the West of Scotland Research Ethics Committee 3 (19/WS/0118); by the Human Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (HREC REF:095/2018); and the NHS, Invasive or Clinical Research Committee at the University of Stirling (NICR:17/18).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and/or analyzed during the current study are not publicly available due to data sharing guidelines from the funders. All data and supporting documentation are available from the corresponding author on reasonable request.

Acknowledgments: The authors would like to thank all participants who volunteered for this project. We would also like to thank our research workers Rasematla Sina Motadi and Nandi Magwaca involved in the South African investigation. We would also like to thank our volunteer master students Megan Ronnie, Emily Aitken, Rachel Johnstone, and Prashasti Nahata involved in the Scottish data collection.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Beard, J.R.; Officer, A.; de Carvalho, I.A.; Sadana, R.; Pot, A.M.; Michel, J.-P.; Chatterji, S. The World report on ageing and health: A policy framework for healthy ageing. *Lancet* **2016**, *387*, 2145–2154. [CrossRef]
2. Curtis, E.; Litwic, A.; Cooper, C.; Dennison, E. Determinants of Muscle and Bone Aging. *J. Cell. Physiol.* **2015**, *230*, 2618–2625. [CrossRef] [PubMed]
3. Nielsen, B.R.; Abdulla, J.; Andersen, H.E.; Schwarz, P.; Suetta, C. Sarcopenia and osteoporosis in older people: A systematic review and meta-analysis. *Eur. Geriatr. Med.* **2018**, *9*, 419–434. [CrossRef]
4. Cruz-Jentoft, A.J.; Bahat, G.; Bauer, J.; Boirie, Y.; Bruyere, O.; Cederholm, T. the Extended Group for, E. Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing* **2019**, *48*, 16–31. [CrossRef] [PubMed]
5. Anton, S.D.; Woods, A.J.; Ashizawa, T.; Barb, D.; Buford, T.W.; Carter, C.S.; Clark, D.J.; Cohen, R.A.; Corbett, D.B.; Cruz-Almeida, Y.; et al. Successful aging: Advancing the science of physical independence in older adults. *Ageing Res. Rev.* **2015**, *24 Pt B*, 304–327. [CrossRef]
6. Chastin, S.; Abaraogu, U.; Bourgois, J.; Dall, P.; Darnborough, J.; Duncan, E.; Dumortier, J.; Jiménez Pavón, D.; McParland, J.; Roberts, N.; et al. Physical Activity, Immune Function and Risk of Community Acquired Infectious Disease in the General Population: Systematic Review and Meta-Analysis. *SSRN* **2020**. [CrossRef]
7. Dumuid, D.; Lewis, L.K.; Olds, T.S.; Maher, C.; Bondarenko, C.; Norton, L. Relationships between older adults' use of time and cardio-respiratory fitness, obesity and cardio-metabolic risk: A compositional isotemporal substitution analysis. *Maturitas* **2018**, *110*, 104–110. [CrossRef]
8. Biddle, G.J.H.; Edwardson, C.L.; Henson, J.; Davies, M.J.; Khunti, K.; Rowlands, A.V.; Yates, T. Associations of Physical Behaviours and Behavioural Reallocations with Markers of Metabolic Health: A Compositional Data Analysis. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2280. [CrossRef]
9. Curtis, R.G.; Dumuid, D.; Olds, T.; Plotnikoff, R.; Vandelanotte, C.; Ryan, J.; Maher, C. The Association Between Time-Use Behaviors and Physical and Mental Well-Being in Adults: A Compositional Isotemporal Substitution Analysis. *J. Phys. Act. Health* **2020**, *17*, 197–203. [CrossRef]
10. Sanchez-Sanchez, J.L.; Manas, A.; Garcia-Garcia, F.J.; Ara, I.; Carnicero, J.A.; Walter, S.; Rodriguez-Manas, L. Sedentary behavior, physical activity, and sarcopenia among older adults in the TSHA: Isotemporal substitution model. *J. Cachexia Sarcopenia Muscle* **2019**, *10*, 188–198. [CrossRef]
11. Ng, C.A.; Scott, D.; Seibel, M.J.; Cumming, R.G.; Naganathan, V.; Blyth, F.M.; Hirani, V. Higher-Impact Physical Activity Is Associated with Maintenance of Bone Mineral Density but Not Reduced Incident Falls or Fractures in Older Men: The Concord Health and Aging in Men Project. *J. Bone Miner Res.* **2020**. [CrossRef]

12. Buford, T.W.; Anton, S.D.; Judge, A.R.; Marzetti, E.; Wohlgemuth, S.E.; Carter, C.S.; Manini, T.M. Models of accelerated sarcopenia: Critical pieces for solving the puzzle of age-related muscle atrophy. *Ageing Res. Rev.* **2010**, *9*, 369–383. [CrossRef]
13. Jain, R.K.; Vokes, T. Physical activity as measured by accelerometer in NHANES 2005–2006 is associated with better bone density and trabecular bone score in older adults. *Arch. Osteoporos.* **2019**, *14*, 29. [CrossRef]
14. Yakabe, M.; Hosoi, T.; Akishita, M.; Ogawa, S. Updated concept of sarcopenia based on muscle-bone relationship. *J. Bone Min. Metab.* **2020**, *38*, 7–13. [CrossRef] [PubMed]
15. Patel, H.P.; Dawson, A.; Westbury, L.D.; Hasnaoui, G.; Syddall, H.E.; Shaw, S.; Dennison, E.M. Muscle Mass, Muscle Morphology and Bone Health Among Community-Dwelling Older Men: Findings from the Hertfordshire Sarcopenia Study (HSS). *Calcif. Tissue Int.* **2018**, *103*, 35–43. [CrossRef]
16. Bull, F.C.; Al-Ansari, S.S.; Biddle, S.; Borodulin, K.; Buman, M.P.; Cardon, G.; Willumsen, J.F. World Health Organization 2020 guidelines on physical activity and sedentary behavior. *Br. J. Sports Med.* **2020**, *54*, 1451–1462. [CrossRef] [PubMed]
17. Gidlow, C.; Johnston, L.H.; Crone, D.; Ellis, N.; James, D. A systematic review of the relationship between socio-economic position and physical activity. *Health Educ. J.* **2016**, *65*, 338–367. [CrossRef]
18. Barr, A.L.; Partap, U.; Young, E.H.; Agoudavi, K.; Balde, N.; Kagaruki, G.B.; Mayige, M.T.; Longo-Mbenza, B.; Mutungi, G.; Mwalim, O.; et al. Sociodemographic inequities associated with participation in leisure-time physical activity in sub-Saharan Africa: An individual participant data meta-analysis. *BMC Public Health* **2020**, *20*, 1–13. [CrossRef]
19. Kolbe-Alexander, T.L.; Pacheco, K.; Tomaz, S.A.; Karpul, D.; Lambert, E.V. The relationship between the built environment and habitual levels of physical activity in South African older adults: A pilot study. *BMC Public Health* **2015**, *15*, 518. [CrossRef]
20. Strain, T.; Fitzsimons, C.; Foster, C.; Mutrie, N.; Townsend, N.; Kelly, P. Age-related comparisons by sex in the domains of aerobic physical activity for adults in Scotland. *Prev. Med. Rep.* **2016**, *3*, 90–97. [CrossRef] [PubMed]
21. Strain, T.; Wijndaele, K.; Garcia, L.; Cowan, M.; Guthold, R.; Brage, S.; Bull, F.C. Levels of domain-specific physical activity at work, in the household, for travel and for leisure among 327,789 adults from 104 countries. *Br. J. Sports Med.* **2020**, *54*, 1488–1497. [CrossRef]
22. Gradidge, P.J.L.; Crowther, N.J.; Chirwa, E.D.; Norris, S.A.; Micklesfield, L.K. Patterns, levels and correlates of self-reported physical activity in urban black Soweto women. *BMC Public Health* **2014**, *14*, 934. [CrossRef]
23. Rae, D.E.; Pienaar, P.R.; Henst, R.H.; Roden, L.C.; Goedecke, J.H. Associations between long self-reported sleep, obesity and insulin resistance in a cohort of premenopausal black and white South African women. *Sleep Health* **2018**, *4*, 558–564. [CrossRef]
24. Shisana, O.; Labadarios, D.; Rehle, T.; Simbayi, L.; Zuma, K.; Dhansay, A.; Reddy, P.; Parker, W.; Hoosain, E.; Naidoo, P.; et al. *The South African National Health and Nutrition Examination Survey, 2012: SANHANES-1: The Health and Nutritional Status of the Nation*; HSRC Press: Cape Town, South Africa, 2014.
25. Mafuya, N.; Peltzer, K.; Chirinda, W.; Musekiwa, A.; Kose, Z.; Hoosain, E.; Davids, A.; Ramlagan, S. Self-reported prevalence of chronic non-communicable diseases and associated factors among older adults in South Africa. *Global Health Action* **2013**, *6*, 20936. [CrossRef] [PubMed]
26. McLean, J.; Dean, L.; Cheong, C.K.; Dougall, I.; Hinchcliffe, S.; Mirani, K.; Vosnaki, K.; Wilson, V. *The Scottish Health Survey*, 2018 ed.; Main Report; 2018; Volume 1. Available online: https://www.gov.scot/publications/scottish-health-survey-2018-volume-1-main-report/ (accessed on 7 February 2021).
27. Mayosi, B.M.; Flisher, A.J.; Lalloo, U.G.; Sitas, F.; Tollman, S.M.; Bradshaw, D. The burden of non-communicable diseases in South Africa. *Lancet* **2009**, *374*, 934–947. [CrossRef]
28. Chastin, S.F.; Palarea-Albaladejo, J.; Dontje, M.L.; Skelton, D.A. Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach. *PLoS ONE* **2015**, *10*, e0139984. [CrossRef] [PubMed]
29. World Bank. *New World Bank Country Classifications by Income Level: 2020–2021*; World Bank: Washington, DC, USA, 2020.
30. Kowal, P.; Dowd, J.E. *Definition of an Older Person. Proposed Working Definition of an Older Person in Africa for the MDS Project*; World Health Organization: Geneva, Switzerland, 2001; pp. 5188–9286.
31. General Assembly of the World Medical Association. World Medical Association Declaration of Helsinki, Ethical Principles for Medical Research Involving Human Subjects. *J. Am. Coll. Dent.* **2014**, *81*, 14–18.
32. World Health Organization. *Obesity: Preventing and Managing the Global Epidemic*; World Health Organization: Geneva, Switzerland, 1998; p. 276.
33. Studenski, S.A.; Peters, K.W.; Alley, D.E.; Cawthon, P.M.; McLean, R.R.; Harris, T.B.; Vassileva, M.T. The FNIH sarcopenia project: Rationale, study description, conference recommendations, and final estimates. *J. Gerontol. A Biol. Sci. Med. Sci.* **2014**, *69*, 547–558. [CrossRef]
34. Looker, A.C.; Borrud, L.G.; Hughes, J.P.; Fan, B.; Shepherd, J.A.; Melton, L. J, 3rd. Lumbar spine and proximal femur bone mineral density, bone mineral content, and bone area, United States, 2005–2008. *Vital Health Stat 11* **2012**, *251*, 1–132.
35. Shuhart, C.R.; Yeap, S.S.; Anderson, P.A.; Jankowski, L.G.; Lewiecki, E.M.; Morse, L.R.; Shepherd, J.A. Executive Summary of the 2019 ISCD Position Development Conference on Monitoring Treatment, DXA Cross-calibration and Least Significant Change, Spinal Cord Injury, Peri-prosthetic and Orthopedic Bone Health, Transgender Medicine, and Pediatrics. *J. Clin. Densitom.* **2019**, *22*, 453–471. [CrossRef]
36. Sousa-Santos, A.R.; Amaral, T.F. Differences in handgrip strength protocols to identify sarcopenia and frailty-a systematic review. *BMC Geriatr.* **2017**, *17*, 238. [CrossRef]

37. Duncan, R.P.; Combs-Miller, S.A.; McNeely, M.E.; Leddy, A.L.; Cavanaugh, J.T.; Dibble, L.E.; Ellis, T.D.; Ford, M.P.; Foreman, K.B.; Earhart, G.M. Are the average gait speeds during the 10 meter and 6 minute walk tests redundant in Parkinson disease? *Gait Posture* **2017**, *52*, 178–182. [CrossRef]
38. Duncan, M.J.; Rowlands, A.; Lawson, C.; Leddington Wright, S.; Hill, M.; Morris, M.; Tallis, J. Using accelerometry to classify physical activity intensity in older adults: What is the optimal wear-site? *Eur. J. Sport Sci.* **2020**, *20*, 1131–1139. [CrossRef] [PubMed]
39. Chow, C.M.; Wong, S.N.; Shin, M.; Maddox, R.G.; Feilds, K.L.; Paxton, K.; Steinbeck, K. Defining the rest interval associated with the main sleep period in actigraph scoring. *Nat. Sci. Sleep* **2016**, *8*, 321–328. [CrossRef]
40. Troiano, R.P.; Berrigan, D.; Dodd, K.W.; Masse, L.C.; Tilert, T.; McDowell, M. Physical activity in the United States measured by accelerometer. *Med. Sci. Sports Exerc.* **2008**, *40*, 181–188. [CrossRef]
41. Hirshkowitz, M.; Whiton, K.; Albert, S.M.; Alessi, C.; Bruni, O.; DonCarlos, L.; Adams Hillard, P.J. National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. *Sleep Health* **2015**, *1*, 40–43. [CrossRef]
42. Buysse, D.J.; Reynolds, C.F., III; Monk, T.H.; Berman, S.R.; Kupfer, D.J. The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Res.* **1989**, *28*, 193–213. [CrossRef]
43. Aloba, O.O.; Adewuya, A.O.; Ola, B.A.; Mapayi, B.M. Validity of the Pittsburgh sleep quality index (PSQI) among Nigerian university students. *Sleep Med.* **2007**, *8*, 266–270. [CrossRef] [PubMed]
44. McGregor, D.; Chastin, S.F.M.; Dall, P.; Palarea-Albaladejo, J. *Physical Activity CoDa Regression Model (PACRM)*; OpenCoDa: Glasgow, UK, 2018.
45. Gupta, N.; Mathiassen, S.E.; Mateu-Figueras, G.; Heiden, M.; Hallman, D.M.; Jorgensen, M.B.; Holtermann, A. A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behavior and physical activity. *Int. J. Behav. Nutr. Phys. Act.* **2018**, *15*, 53. [CrossRef]
46. Scott, D.; Johansson, J.; Gandham, A.; Ebeling, P.R.; Nordstrom, P.; Nordstrom, A. Associations of accelerometer-determined physical activity and sedentary behavior with sarcopenia and incident falls over 12 months in community-dwelling Swedish older adults. *J. Sport Health Sci.* **2020**. [CrossRef]
47. Msambichaka, B.; Abdul, R.; Abdulla, S.; Klatser, P.; Tanner, M.; Kaushik, R.; Bringolf-Isler, B.; Geubbels, E.; Eze, I.C. A cross-sectional examination of physical activity levels and their socio-demographic determinants in Southern Tanzania. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1054. [CrossRef]
48. Guthold, R.; Louazani, S.A.; Riley, L.M.; Cowan, M.J.; Bovet, P.; Damasceno, A.; Sambo, B.H.; Tesfaye, F.; Armstrong, T.P. Physical activity in 22 African countries: Results from the World Health Organization STEPwise approach to chronic disease risk factor surveillance. *Am. J. Prev. Med.* **2011**, *41*, 52–60. [CrossRef] [PubMed]
49. Cook, I.; Alberts, M.; Brits, J.S.; Choma, S.R.; Mkhonto, S.S. Descriptive epidemiology of ambulatory activity in rural, black South Africans. *Med. Sci. Sports Exerc.* **2010**, *42*, 1261–1268. [CrossRef]
50. Foong, Y.C.; Chherawala, N.; Aitken, D.; Scott, D.; Winzenberg, T.; Jones, G. Accelerometer-determined physical activity, muscle mass, and leg strength in community-dwelling older adults. *J. Cachexia Sarcopenia Muscle* **2016**, *7*, 275–283. [CrossRef] [PubMed]
51. Langsetmo, L.; Hitchcock, C.L.; Kingwell, E.J.; Davison, K.S.; Berger, C.; Forsmo, S.; Canadian Multicentre Osteoporosis Study Research, G. Physical activity, body mass index and bone mineral density-associations in a prospective population-based cohort of women and men: The Canadian Multicentre Osteoporosis Study (CaMos). *Bone* **2012**, *50*, 401–408. [CrossRef] [PubMed]
52. Onambele-Pearson, G.; Wullems, J.; Doody, C.; Ryan, D.; Morse, C.; Degens, H. Influence of Habitual Physical Behavior—Sleeping, Sedentarism, Physical Activity—On Bone Health in Community-Dwelling Older People. *Front. Physiol.* **2019**, *10*, 408. [CrossRef]
53. Rodriguez-Gomez, I.; Manas, A.; Losa-Reyna, J.; Rodriguez-Manas, L.; Chastin, S.F.M.; Alegre, L.M.; Ara, I. Associations between sedentary time, physical activity and bone health among older people using compositional data analysis. *PLoS ONE* **2018**, *13*, e0206013. [CrossRef] [PubMed]
54. Chantler, S.; Dickie, K.; Goedecke, J.H.; Levitt, N.S.; Lambert, E.V.; Evans, J.; Joffe, Y.; Micklesfield, L.K. Site-specific differences in bone mineral density in black and white premenopausal South African women. *Osteoporos. Int.* **2012**, *23*, 533–542. [CrossRef]
55. Shad, B.J.; Wallis, G.; van Loon, L.J.; Thompson, J.L. Exercise prescription for the older population: The interactions between physical activity, sedentary time, and adequate nutrition in maintaining musculoskeletal health. *Maturitas* **2016**, *93*, 78–82. [CrossRef]
56. Pinheiro, M.B.; Oliveira, J.; Bauman, A.; Fairhall, N.; Kwok, W.; Sherrington, C. Evidence on physical activity and osteoporosis prevention for people aged 65+ years: A systematic review to inform the WHO guidelines on physical activity and sedentary behavior. *Int. J. Behav. Nutr. Phys. Act.* **2020**, *17*, 1–53. [CrossRef]
57. Chastin, S.F.; Mandrichenko, O.; Helbostadt, J.L.; Skelton, D.A. Associations between objectively-measured sedentary behavior and physical activity with bone mineral density in adults and older adults, the NHANES study. *Bone* **2014**, *64*, 254–262. [CrossRef]
58. Kim, Y.; White, T.; Wijndaele, K.; Sharp, S.J.; Wareham, N.J.; Brage, S. Adiposity and grip strength as long-term predictors of objectively measured physical activity in 93 015 adults: The UK Biobank study. *Int. J. Obes.* **2017**, *41*, 1361–1368. [CrossRef] [PubMed]
59. Bohannon, R.W. Grip Strength: An Indispensable Biomarker for Older Adults. *Clin. Interv. Aging* **2019**, *14*, 1681–1691. [CrossRef] [PubMed]
60. Luo, Y.; Jiang, K.; He, M. Association between grip strength and bone mineral density in general US population of NHANES 2013–2014. *Arch. Osteoporos.* **2020**, *15*, 47. [CrossRef]

61. He, C.; He, W.; Hou, J.; Chen, K.; Huang, M.; Yang, M.; Luo, X.; Li, C. Bone and Muscle Crosstalk in Aging. *Front. Cell Dev. Biol.* **2020**, *8*. [CrossRef] [PubMed]
62. Chopra, S.; Morrow, M.M.; Ngufor, C.; Fortune, E. Differences in Physical Activity and Sedentary Behavior Patterns of Post-menopausal Women with Normal vs. Low Total Hip Bone Mineral Density. *Front Sports Act Living* **2020**, *2*. [CrossRef] [PubMed]
63. Fragala, M.S.; Cadore, E.L.; Dorgo, S.; Izquierdo, M.; Kraemer, W.J.; Peterson, M.D.; Ryan, E.D. Resistance Training for Older Adults: Position Statement From the National Strength and Conditioning Association. *J. Strength Cond. Res.* **2019**, *33*, 2019–2052. [CrossRef] [PubMed]
64. Smit, W.; de Lannoy, A.; Dover, R.V.; Lambert, E.V.; Levitt, N.; Watson, V. Making unhealthy places: The built environment and non-communicable diseases in Khayelitsha, Cape Town. *Health Place* **2016**, *39*, 196–203. [CrossRef] [PubMed]
65. Lambert, E.V.; Kolbe-Alexander, T.; Adlakha, D.; Oyeyemi, A.; Anokye, N.K.; Goenka, S.; Salvo, D. Making the case for 'physical activity security': The 2020 WHO guidelines on physical activity and sedentary behavior from a Global South perspective. *Br. J. Sports Med.* **2020**, *54*, 1447–1448. [CrossRef]
66. Dempsey, P.C.; Biddle, S.J.; Buman, M.P.; Chastin, S.; Ekelund, U.; Friedenreich, C.M.; Bull, F. New global guidelines on sedentary behavior and health for adults: Broadening the behavioural targets. *Int. J. Behav. Nutr. Phys. Act.* **2020**, *17*, 1–12. [CrossRef]
67. Chiba, R.; Ohashi, Y.; Ozaki, A. Sleep disturbances in adults with frailty and sarcopenia. *Qual. Ageing Older Adults* **2020**, *21*, 89–107. [CrossRef]
68. Bevilacqua, G.; Denison, H.J.; Laskou, F.; Jameson, K.A.; Ward, K.A.; Cooper, C.; Dennison, E.M. Self-reported Sleep Quality and Bone Outcomes in Older Adults: Findings from the Hertfordshire Cohort Study. *Calcif. Tissue Int.* **2020**, *106*, 455–464. [CrossRef] [PubMed]
69. Peberdy, S.; Majodina, Z. Just a roof over my head? *Urban Forum* **2000**, *11*, 273–288. [CrossRef]
70. Moolla, R.; Kotze, N.; Block, L. Housing satisfaction and quality of life in RDP houses in Braamfischerville, Soweto: A South African case study. *Urbani Izziv* **2011**, *22*, 138–143. [CrossRef]
71. Gadie, A.; Shafto, M.; Leng, Y.; Kievit, R.A.; Cam, C.A.N. How are age-related differences in sleep quality associated with health outcomes? An epidemiological investigation in a UK cohort of 2406 adults. *BMJ Open* **2017**, *7*, e014920. [CrossRef] [PubMed]